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GRANVILLE, OHIO, APRIL, 1911

THE ABANDONED SHORELINES OF THE VERMILION QUADRANGLE, OHIO[1]

FRANK CARNEY

The literature contains a few references specifically to the raised beaches of this sheet. One is by M. C. Read[2] who published a cross-section of some terraces near Berlin Heights; another is by E. E. Wright[3] whose map of the lake ridges in Lorain and Cuyahoga counties roughly locates some of the ridges east of the Vermilion River; and they have been studied in places by F. Leverett[4] who briefly describes them.

Compared with adjacent sheets, the Vermilion has an irregular surface. The position of the Berea sandstone accounts for this fact; this formation outcrops across the northern part of the quadrangle (fig. 1), and its escarpment has been made very irregular by ancient stream erosion; as a result, many outliers exist. The area contains one major stream, the Vermilion River, which during post-glacial times has easily made a new base-level for many of the illy defined pre-glacial valleys. Should the history of this river be worked out, it is probable that its channel will be found, in parts at least, to represent pre-Wisconsin stream work.

From the level of Lake Erie, 573 feet, the surface of the sheet rises rapidly to the south. Away from the axis of the Vermilion River, the 800-foot contour nowhere is more than six miles south of the lake. Because of this fact, the abandoned shore lines are close together; they are found usually within a limit of two miles. These raised beaches lie so close together here because the Berea formation is so very thick. At the South Amherst quarries, which are located one and a half miles southeast of Brownhelm, the Berea has a thickness of over 200 feet. I have no data as to the exact

[1] Read by title before Section E of the American Association for Advancement of Science, Boston, Dec., 1909, with the permission of the State Geologist of Ohio. The author is responsible for the facts given.

[2] *Geological Survey of Ohio*, vol. iii, p. 289. 1878.

[3] *Ibid.*, vol. ii, map opposite p. 58. 1874.

[4] *Monograph*, xli, United States Geological Survey, pp. 732–733, 751. 1902.

thickness of this formation at Berlin Heights, but from the base of the escarpment to the highest point nearby where Berea rock exists, there is an interval of about 150 feet. In addition to this stratigraphic influence in bringing these old shore lines within a narrow horizontal range, the rock structure has also been a very strong factor in both the texture and the outline of the Whittlesey and Maumee beaches.

The Maumee Shore Line

West of the Vermilion quadrangle these beaches trend to the south, on account of a bay which occupied the depression followed by the Huron River. Southeast of Berlin Heights, it is evident that the Maumee, during its earliest period, had an altitude of 780–790 feet. This position did not last long, but the multiplicity of disconnected ridges, and the great number of dunes at slightly higher altitudes, are evidence of wave-produced sand. Disconnected ridges are found also west and north of Florence. It is possible that they represent the work of a small local body of water along the front of the ice previous to the Maumee stage.

About Berlin Heights the shore structures are very irregular, a condition due to the dissection of the Berea. The high rock hills, which suggested the name of "Berlin Heights" furnished the waves an inexhaustible supply of sand. During the early Maumee stage these hills were islands and from their sides spits were developed, especially to the south and west, and winds shifted the sand into dunes making accurate mapping of the original beaches quite impossible.

Extending northeast from the "corners" in Berlin Heights is an extensive deposit of coarse beach gravel from which, several years ago, railroad ballast was taken. I have not found it possible to distinguish the two Maumee levels here, because the area has been so mutilated in removing the gravel.

Eastward from the quarry, located in the northernmost of these Berea outliers, a complex arrangement of sand and gravel ridges extends to and beyond Ogontz. The highest of these, which crosses the roadway about one-half mile south of Ogontz, is strong; it clearly represents the upper Maumee level. The shore line here at first curved to the south in a bay which was eventually shut off by the growth of a spit. The first spit-development

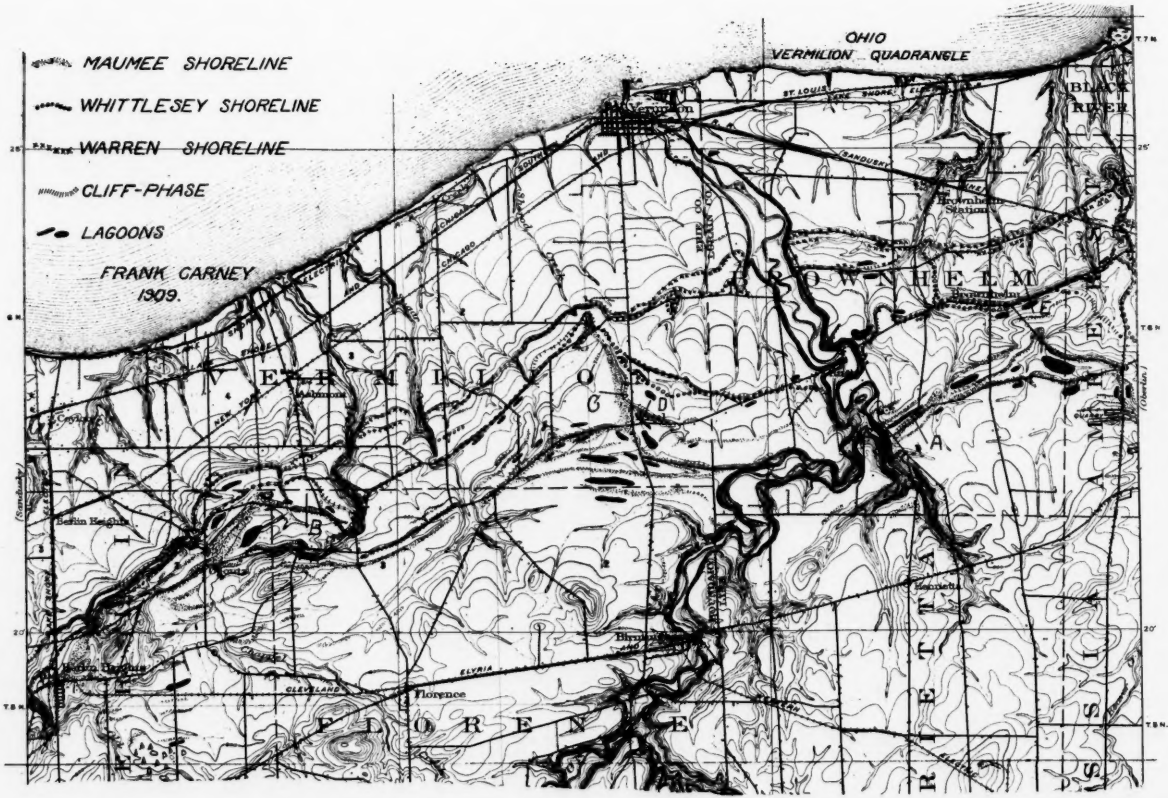


FIG. 1 Scale is Approximately $\frac{1}{126000}$. The Small Triangles Indicate Sand Dunes.

proceeded eastward over one-quarter of a mile; the second one, which eventually became the shore line, is followed by the highway from Berlin Heights to Ogontz. This beach eastward is quite parallel to the earliest ridge; Chappel Creek flows between the two. Just south of this area is another outlier of Berea sandstone which has an altitude of 830 feet; this afforded a good supply of beach material. North of this outlier the beach developed a cusp; eastward the shore line at first turned to the south; later, however, this irregularity was straightened, leaving the earlier ridge isolated. From this vicinity eastward for nearly two miles the Maumee beaches are parallel; locally they have been united by wind-drifted sand.

At a point about two miles west of the Vermilion River the shore line of the upper level again becomes very irregular. This condition is due probably to the two factors: one, abundance of beach material supplied by outcropping sandstone; the other, the slight bay in the depression now occupied by the Vermilion River, which the shore line tended to straighten. At first this bay was approximately two miles deep, extending south to the vicinity of Birmingham; but this stage did not last long because of the growth of spits from the western angle of the bay; enough gravel and sand, however, has been found in scattered segments to establish its early outline. The numerous lagoons, forming in parallel series, show the successive development of spits into bars before this Maumee shore line became stable. So far as can be inferred from a study of the ridges, it seems evident that the final position of the upper beach here was strong enough to account for the east-west direction of the Vermilion River for about a mile. I have mapped this ridge a little east of the angle where the river turns south, but have hesitated to carry it farther eastward because so much of the beach materials has been removed by the under-cutting of the stream. That there was abundant gravel and sand farther east of it, however, is shown at disconnected points, especially in the pre-historic earth works about one-quarter of a mile east of the highway that rises northward up out of the river valley.

On the east side of the Vermilion River the highway trending a little north of east follows the upper Maumee shore line. Throughout the whole of this distance the beach is very distinctly marked, and has been cut by recent drainage at only one point; for the first mile, there are two distinct ridges (fig. 2A). Near the

eastern margin of the sheet the Maumee beach turns directly south, bordering a bay in the Beaver Creek depression of the Oberlin sheet.[5] The extensive quarrying operations at South Amherst have made definite mapping of the beach in this locality impossible. Through part of the distance the shore gravels have probably been removed, and elsewhere the dump of quarry rubbish has covered up the beach; locally the shore line was registered by a cliff in the sandstone which has been quarried. I have mapped shore gravels and one lagoon near these quarries at an altitude, according to the topographic sheet, at least 10 feet higher than the Maumee level elsewhere. It is very likely that a slight error has been made here in sketching the topography. In texture, the entire length of this beach east of the Vermilion River is prevailingly fine.

LOWER MAUMEE

As already suggested, it is impossible at some points to distinguish the two Maumee levels. This condition is due largely to dune deposits, though post-glacial weathering may be a contributing factor.

Extending eastward from the rock hills near Berlin Heights the shore line of the lower Maumee level forms a distinct ridge to the vicinity of Ogontz; within this distance are two short spits which developed from cusps. Just east of Ogontz the two shore lines blend because of a cusp built out from the higher level, to which the lower beach was joined, the difference in level having been rendered less distinct by wind deposits. From this point, the lower Maumee beach bears northward; through part of the distance it is a little over a quarter of a mile wide, and consists mostly of very coarse material. The 750-foot contour outlines the beach until it turns again eastward. At the angle of the turn there is a spit, separated from the shore proper by a lagoon. Post-glacial drainage has cut through the beach just east. Continuing as a single ridge (fig. 2B), it is followed by a highway to the edge of Chappel Creek. In this area a small bay marked the lower Maumee level as is shown by the turn in the beach as well as by a spit, about one-quarter mile long, built eastward from this angle.

On the east side of Chappel Creek the lower shore line for a

[5] Pp. 101–117.

distance of about one and one-half miles is followed by a highway and is parallel to the beach of the upper level. An off-shore barrier, about one-half mile long, shows in this distance. Both beach ridges have been cut by Sugar Creek, east of which the same parallel relationship persists.

After crossing Darby Creek the lower shore line is not distinct. Through part of this distance the Berea sandstone has a cliff which may represent wave-work, but it is not sufficiently continuous to warrant so mapping. It is evident that here the lower level was made irregular by a cape extending nearly a mile into the lake. A beach ridge on its eastern side is continuous to the promontory of Berea sandstone in which the cape terminated. Extending a short distance to the southwest from the promontory there is also a strong beach ridge which terminates in a hook bent to the east. This relationship suggests that the promontory, in which the cape terminates, may have been an island early in the Maumee level, and that as the lake level fell it was tied to the shore line, the bar becoming a beach ridge. North of Axtel, wave-work cut a cliff in the Berea sandstone (fig. 2C); the cliff phase continues southeastward along the beach ridge; this ridge has a sharp development as it trends to the south (fig. 2D). Shortly it turns more directly east, decreasing in height as it nears the river.

On the opposite side of the Vermilion river, the lower Maumee level is near to, and parallel to, the earlier shore line. For the first half-mile the two are separated by a long lagoon. There is another lagoon just north of the lower beach, between it and an off-shore barrier.

Eastward there is some indefiniteness in mapping the beach ridge of this lake level. The highway south from Brownhelm crosses two ridges before reaching the shore of the upper level. The first of these ridges consists of too coarse material to permit its interpretation as an off-shore barrier; the second is so fine in texture that it may be a barrier of the higher level, but at its eastern end it blends into a cliff cut in the sandstone, which is probably contemporaneous in origin with the ridge first alluded to. At the next highway a cusp-like deposit of prevailingly coarse beach materials extends for a short distance northward. From this point nearly to the edge of the sheet a highway follows this beach. At the north-south highway it turns southward parallel to the ridge already described.

The Whittlesey Shore Line

Lake Whittlesey marks a decline of about 30 feet from the lower Maumee level. Its shore line is generally parallel to the Maumee ridges; and, in the western third of the sheet, very close to them.

In the vicinity of Berlin Heights this shore line consists of a beach ridge, rather coarse in texture. The nearness of a supply of sandstone and the fact that the shore line trends to the southwest, an alignment due to Huron bay on the Sandusky sheet,

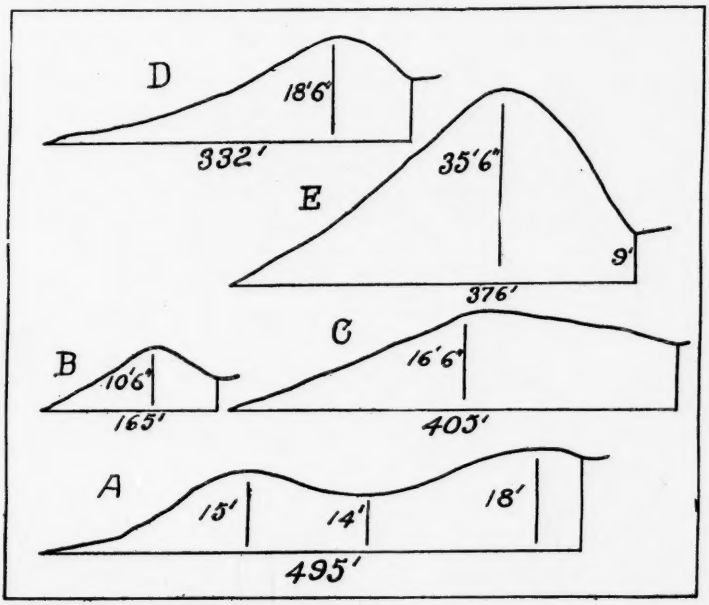


Fig. 2 Consult Fig. 1 for the Location of these Cross-Sections. In Each Case, the Left Side is the Water Slope.

account in part for the coarse texture. The beach materials become finer as the ridge turns to the east. For a short distance next, its location is not definite, though apparently it is followed by the railroad siding to the stone quarry. Eastward from the quarry the Whittlesey is a well developed beach ridge, and thus continues for about a mile when it becomes a cliff cut around the northern slope of a Berea outlier, the top of which is covered with Maumee sands and gravels.

On the east side of Cranberry Creek, the Whittlesey level is defined by a beach ridge trending slightly to the north, for about one and a half miles. Then the shore line becomes a cliff, and bears southward into the Chappel Creek depression. Eastward from this creek, a highway follows the Whittlesey beach to within a short distance of the conspicuous cape of the Maumee level, already described. Through most of this course of three miles, the shore line consists of a typically developed beach ridge; but nearing the east end it becomes a cut cliff. The degree of development of this beach is shown also in the numerous lagoons that border its landward side. Two positions of the shore line are indicated near the cape: the earlier is entirely structural; the later, a short distance north, is cut in the sandstone. Eastward, however, beach gravels prevail almost to the point of the cape. Wavework of the Whittlesey stage must have cut this cape back some distance; Maumee gravels are found up to the very edge of the cliff.

On the east side of this cape the Whittlesey shore line turns southward, and consists entirely of structural materials. Between the two highways the ridge is coarse in texture. Nearing the eastern of these roads two ridges are shown, separated by a lagoon: the earlier one was of short duration, and registers a southward bend in the lake shore; the later position is a strongly developed ridge, now followed by a highway. The two ridges come together near the Erie-Lorain county boundary. From this point to the gorge of the Vermilion River, the Whittlesey level has a sharply developed beach ridge.

On the opposite side of the river, this beach parallels the river for a distance of about 80 rods; the stream is now removing shore gravels as it undercuts the shale beneath. The beach ridge, as the shore line turns northward, blends into a sandstone cliff; this cape was used as a triangulation station. The highway, eastward to Brownhelm, follows the Whittlesey shore line. In the vicinity of Brownhelm the beach ridge is double.

About one mile east of this place, the earliest course of the shore line extended to the southeast, a position now marked by a low cliff cut into the sandstone; this, however, was a temporary position. Its isolation came about as follows, but the sequence is merely suggestive: east of Quarry Run are two Berea outliers, one of which is almost entirely on the Oberlin sheet: these were

islands in the early part of the Whittlesey period; spits were developed from them; the spit reaching to the southwest appears to have been tied first to the shore. Then the Whittlesey shore line from Brownhelm trended northward. The two islands had already been united by bars. A spit grew southward from the one on the Oberlin sheet, eventually tying the islands again to the shore. These outliers, thus doubly tied, formed a cape. The northern shore of the first island, and both the northern and eastern shores of the second island, were cliffed by the Whittlesey waters.

About one-half mile east of Brownhelm, the Whittlesey beach has the most pronounced development noted anywhere on the sheet (fig. 2E). The steep landward slope of this ridge must represent some post-glacial stream erosion.

ISLANDS

In addition to the above islands, which early became a part of the shore line proper, three others are noted. One is northwest of Brownhelm; it was eventually tied to the shore line; the connecting bar is very coarse near the island, but the gravel and cobble become finer southward. On the northern part of this island, was opened one of the earliest Berea quarries in this region.

About a mile west of the Vermilion River, near the Warren shore line is another island of Berea sandstone. This is completely surrounded by beach materials. On its western side successive spits, growing southward, enclosed lagoons as indicated on my map.

Near the east side of the sheet, a spur from the Lake Shore railroad reaches a quarry one mile north. This quarry is in an outlier of the Berea, the top of which was slightly above the Whittlesey level; it bears a ridge of gravel, but I did not note any cliff-cutting.

The Warren Shore Line

Lake Whittlesey dropped 40 feet in the change to the Warren level. Its shore line across half of the sheet is a cliff cut in the Berea sandstone. This cliff-phase is without interruption for the first three miles from the western edge of the sheet; then a cusp of sand extends a short distance northward. Thence to the

east is a mile of sandstone cliff which is varied at the next highway-crossing, directly south of Ashmont, by a ridge of fine materials, originating apparently as a barrier but later forming a beach. From this point to Chappel Creek a cliff-phase marks the Warren level. Eastward from Chappel Creek for most of the distance to Sugar Creek, I have mapped an upper slightly developed ridge blending at the western end with a lower and better developed beach ridge. Eastward from Sugar Creek for nearly three miles a cliff continues. This cliff is particularly sharp directly opposite the cape that existed during both the Maumee and the Whittlesey levels. Between this point and the Vermilion River I have indicated two continuous beach ridges, the upper one of slighter development; their continuity is evidence of successive levels. The lower one may have had its origin in an off-shore barrier, but it served as the beach ridge proper for a longer period than did the upper one.

East of the Vermilion two corresponding ridges exist for one and one-half miles. The inner ridge is irregular at one point, suggesting a cusp development. For part of the distance the outer beach is also composite. Near the river channel I noted deposits apparently representing the growth of spits into the slight bay that preceded the static position of the outer beach.

East of Brownhelm Creek the Warren level is registered by a cliff cut in the Berea outlier which was an island, already described, in the Whittlesey stage. Between this outlier and the one near the eastern edge of the sheet two ridges persist, but they are so close together that I am inclined to regard them as a single beach. Obviously, however, the outer one is a little lower in altitude, and its water-slope, for part of the distance, shows steepening by wave-work. Near the eastern outlier the sand is evidently wind-drifted.

ISLANDS

This outlier was an island in the Whittlesey stage, but of slight area, as already explained. Early in the Warren level it was also an island; later it became a part of the shore line. I have not indicated a position for the beach when this outlier was an island; the area immediately southwest bears so much wind-drifted sand that it is impossible to tell where the original beach may have

been. My mapping gives the final position of the Warren waters. Practically the whole circumference of the island shows cliff-cutting; the cliff along the eastern side is continuous southward, and for most of the distance is a bare rock wall; but just as the shore line swings to the east it becomes beach material, consisting of fine gravel and sand. The outer slope of this beach has been steepened in harmony with the cliff north of it.

Geographic Influence of these Shorelines

The beaches of these former lakes have been factors in the settlement and development of this area, as well as in its occupation by the forerunners of the white man.

HIGHWAYS

As elsewhere in northern Ohio, these ridges carry highways. The proximity of the beaches on the Vermilion sheet accounts for some of the east-west highways being unusually close together. Commencing on the east side of the sheet, each ridge is followed by a road to the Vermilion river. West of the river the Warren shoreline consists almost entirely of a cut cliff; the other two shorelines carry roadbeds except for a few short intervals. The advantages of this use of old shorelines are obvious; a gravel pike is already made, insuring fairly good drainage; furthermore, the same conditions are of advantage to man in locating his dwellings.

AGRICULTURE

Wherever specialized agriculture is in vogue, the influence of these former lake levels on farming is more obvious. This condition, however, does not arise early in the development of an area; proximity to large cities leads to intensified farming. No large cities are very near the Vermilion sheet. The only conspicuous response is fruit growing; hundreds of acres of sandy soil, both the old ridges and their terraces and the adjacent inland areas over which wind has drifted sand, are being devoted to peach orchards. In recent years some progress has been made in truck farming; this is a response to the two electric lines that

afford quick and frequent service to several growing cities. Neither of these electric lines follows the shore ridges, although they are within convenient distance, one north and the other south. The numerous muck areas, noted especially along the Maumee and Whittlesey shorelines, are adapted to market gardening.

ECONOMIC MINERAL PRODUCTS

To some extent these former water bodies have been factors in making the Berea sandstone more accessible. The principal quarry areas now being worked are (1) near Berlin Heights, and (2) southeast of Brownhelm; the latter is generally known as the "Amherst" quarry. Near Berlin Heights the quarry is located in a cliff of the Whittlesey level; this is the older of the two quarries, but the stone does not appear to be as satisfactory as that from the Amherst area. The first Berea sandstone quarry in this part of the state was opened south of Brownhelm station; a crack from the Lake Shore and Michigan Southern Railway afforded good shipping facilities; later, stone of better quality was found elsewhere and this quarry was abandoned. Perhaps the most extensive quarries now being worked in the Berea sandstone are those at Amherst; at no other place in Ohio has such a thickness of the Berea been operated. The structural conditions of this rock horizon are here best suited for quarrying.

The abundant gravel and sand of these shorelines will lead to an increasing local use of cement in making building and other structural blocks, as lumber becomes higher in price. Already one notes the beginning of this use.

The north-south highways, within easy reach of the old beaches, for decades have been coated with the gravel from the shore ridges. At two points, one near Berlin Heights, the other near Ogontz, railroads have removed many acres of beach gravel for ballast.

THERMO-ELECTRIC COUPLES[1]

A. W. Davison

Seebeck discovered the phenomenon of thermo-electricity in 1821. He arranged a series of the metals, the current proceeding through the cold junction in the following order: Antimony to iron, zinc, silver, gold, tin, lead, copper, platinum, bismuth. He also determined that when three or more metals, A, B and C, are in the series, E being the voltage generated, $E_{AC} = E_{AB} + E_{BC}$. In other words, the electromotive force remains the same when a circuit is opened, and a third metal is inserted, provided the temperatures of its ends are the same.

Gaugain found that for any couple, the relationship between the electromotive force and the temperatures can be represented graphically. Kelvin proved these curves to be parabolas, and since the equation for a parabola is $y = ax + bx^2$, in the case under consideration, $E = bt + ct^2$.

Inversion. Since these curves are parabolas, a maximum point, the neutral point, as A (fig. 1), will be reached. For temperatures above this point, the electromotive force will decrease, until t_1 and t_2 are equidistant from, and on opposite sides of, the neutral point, when the electromotive force is zero.

If t_2 is now increased, the electromotive force will be reversed, and "thermo-electro inversion" takes place, the current flowing in the opposite direction. This was proved experimentally by Cumming. Hence from the equation the electromotive force is zero when $t_1 = t_2$, or when $(t_1 + t_2)/2 = -b/2c$.

Thermo-electric power. If we take a lead-metal $(Pb - M)$ couple, whose $E_o^t = bt + ct^2$, and raise t to $(t + dt)$, then $E_o^{t+dt} = b\,(t + dt) + c\,(t + dt)^2$. Now the small electromotive force generated, $dE = E_o^{t+dt} - E_o^t = b \cdot dt + 2ct \cdot dt$.

Thus the rate of increase of electromotive force with temperature $dE/dt = b + 2ct$, is called the thermo-electric power of the

[1] A thesis presented for the Fletcher O. Marsh Prize in Physics, Denison University, June, 1910.

metal M with respect to lead. It is apparent that this is a straight line, and since the lead line is horizontal, we take it as the reference line, and plot the thermo-electric powers of metals with respect to the lead line.

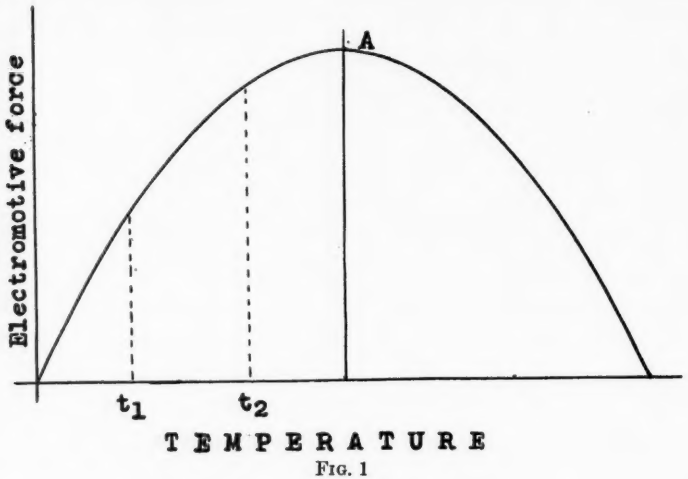


FIG. 1

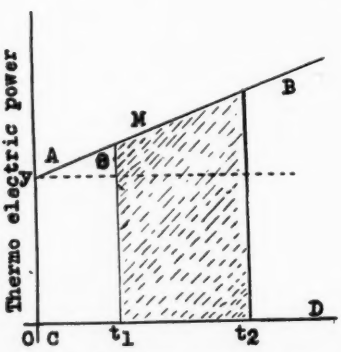


FIG. 2

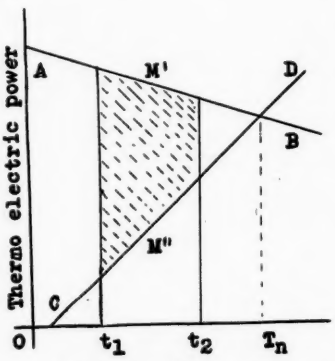


FIG. 3

Thermo-electric diagram. In fig. 2, let CD be the standard lead line, and AB be the thermo-electric power line of metal M. The constant b represents the distance Oy, while $2c$ is the tan-

gent Θ. If $2c$ is negative, the line will slope downward from left to right.

If the junctions are at t_1 and t_2, the shaded area, fig. 2, represents the electromotive force around the circuit, hence for metals M' and M'' fig. 3, the shaded area represents the electromotive force when the junctions are at t_1 and t_2. The ordinate, T_n of the point where the lines cross represents the neutral temperature for those metals. It is customary to represent the thermo-electric power lines of all metals on one sheet, from such a sheet the direction and values of electromotive forces for given temperatures and given metals, as well as neutral points, may be determined.

Peltier effect. Peltier, in 1834, observed that this thermo-electric effect is reversible, that when a current is sent around a circuit whose junctions are at the same temperatures, heat is

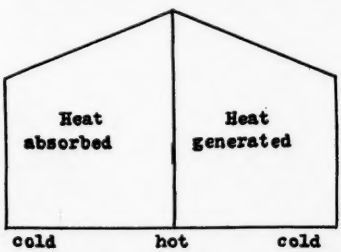


FIG. 4. Thomson Effect. Positive effect. Direction of Current.→ Direction of heat travel.→

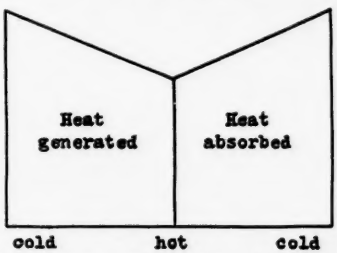


FIG. 5. Thomson Effect. Negative effect. Direction of Current.→ Direction of heat travel.←

absorbed at one junction, and generated at the other. This may be explained by assuming that there is a sudden change of potential at the junctions, which is independent of the battery, and that the current does work in traversing this fall of potential.

Thomson effect (figs. 4 and 5). Lord Kelvin, while trying to apply the reversible cycle of Carnot to the Peltier effect, concluded that were the Peltier effect the only reversible effect in the circuit, the electromotive force of the couple would be directly proportional to the difference in temperature of the junctions, which is contrary to observed facts. This led him, in 1851, to predict the existence of other effects, which he found, and which were named after him, the Thomson effect.

When a current is sent through a conductor whose center is at a higher temperature than the ends, "electrical convection of heat" takes place, in those metals whose thermo-electric lines slope downwards from left to right, the heat travels against the current; while in those whose lines slope upwards, the heat travels with the current.

This transfer of heat is also sometimes called the "specific heat of electricity."

Thermo-dynamics. Fig. 6 is a diagram of a $M-Pb$ couple, with junctions at t_1 and t_2. The area of $P_2OT_2A_2$ represents the energy gained at the hot junction; the area $P_2P_1A_1A_2$ is the energy lost in the M wire due to the Thomson effect; while of course in the lead wire no energy is lost or gained. The area

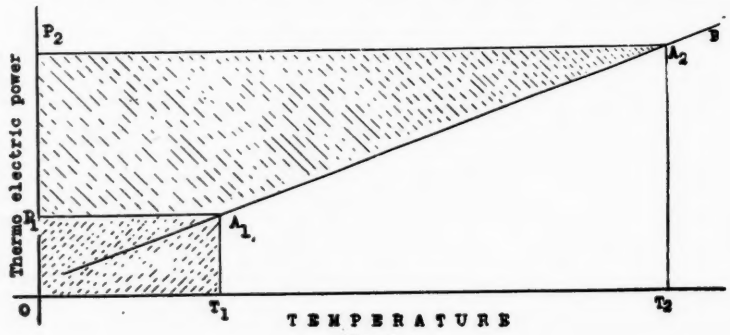


FIG. 6

$P_1O\ T_1A_1$ represents the energy lost at the cold junction, due to the Peltier effect. It is therefore apparent that the area $A_1T_1T_2A_2$ represents the total gain of energy when unit quantity of electricity flows around the circuit.

From the diagram, it is also apparent that the electromotive force of any couple between t_1 and t_2 is equal to the $EMF_{\Theta}^{t_1} + EMF_{t_2}^{\Theta}$. This is called the law of successive temperatures.

Effects of strain, irregularities, etc. Magnus has shown that a circuit of one metal, uniform in state and strain, can have no thermo-electric force, no matter at what temperatures its junctions may be; but impurities, variations in physical condition, strain, alter the effect, even change the series of Seebeck. Different grades of iron and steel show great variations, and many metals give unstable curves under high temperatures.

Alternate hard and soft places, the least oxidation of surfaces, strain, twisting, bending, shear; all contribute to variations, some to a great degree.

The cause of thermo currents. Until the advent of the electron theory, the phenomena of thermo-electricity were without explanation, since it was definitely known that there is no exchange of atoms between the metals. But the electron theory gives a very good explanation of the observed facts.

Let us consider an electron; the best assumptions of J. J. Thomson attribute it to be $\frac{1}{1700}$ of the mass of a hydrogen atom, while the repelling force exercised between two electrons is 10^{43} times greater than the gravitational pull exercised by the same masses. Each electron is a negative charge of electricity, and we consider that when a univalent molecule has two electrons attached, it carries a negative charge; when one, a neutral charge; when none, a positive charge.

The modern view of heat is that it is a rapid motion of the smallest parts of matter, that is, of these electrons, and it has been determined that to raise the temperature of a wire from 0° to 100°, increases the velocity of its electrons 17 per cent.

Just as the pressure of a gas is increased by heating, the "pressure" of the electrons is increased by heating, and they travel into cooler parts, where the "pressure" is less.

When a wire is bent and joined, forming a circuit, and a point of this wire is heated, the electrons move in opposite directions from the hot point; but no current results, since they go in both directions. If, however, the wire on one side of the hot point is cooled, the slope of pressure will be abrupt on that side, and the electrons will pass in that direction. When a thermo-junction is made, the "slope of the heat curve" is altered by joining two metals of different conductivities for heat. If bars of lead and zinc are joined, and the union is heated, this temperature slope is more abrupt on the lead side, so the electrons will pass from zinc to lead. Since these electrons are negative charges, the current of positive electricity is said to pass from lead to zinc.

On the other hand, if a current is sent across a cold junction, the electrons passing from zinc to lead, since there is more resistance in the lead than in the zinc, the electrons must acquire energy from somewhere, which they do from their motion, hence

the junction is cooled. It is at once apparent how, if the electrons are traveling from lead to zinc, the junction will be heated.

But how may we explain thermo-electric inversion, and the neutral point?

Liebenow found that the greater the ratio:—conductivity of heat to conductivity of electricity, the more readily electrons pass from a metal across the hot junction. Also, that "there is an electromotive force generated within the metal which urges the electrons to proceed in the direction in which heat is being propagated." So the electromotive force of a thermo-couple is a differential effect, due to more electrons being dragged along in one metal than in another.

Explanation of neutral point and inversion. In one metal, at definite temperatures, the electromotive force is proportional to $\sqrt{L/S}$, where L is the heat conductivity, and S the electrical conductivity. Now L does not usually vary greatly with temperature, but it is well known that electrical conductivity does; and it is this very thing which causes thermo-electric curves to be other than straight lines, and which causes thermo-electric inversion.

Now in the majority of metals, the quantity $\sqrt{L/S}$ increases with rise in temperature, but in some, as in iron, the ratio diminishes, or reverses upon heating; and the couple passes through a maximum, or is reversed.

For an efficient thermo-couple, two metals are desired whose ratios $\sqrt{L/S}$ are as different as possible, for if as the temperature changes, these ratios become equal, the wandering of the electrons will be the same in both directions, and the neutral point will be reached.

THE DETERMINATION OF THE THERMO-ELECTRIC CHARACTERISTICS OF SAMPLES OF WIRE OBTAINED FROM THE DRIVER-HARRIS WIRE COMPANY

In determining these characteristic quantities, Leeds and Northup Research galvanometer No. 323, and L. & N. Standard Laboratory Wheatstone Bridge No. 5034 were used. To alter the sensibility of the galvanometer, so that various maximum electromotive forces might be determined, the resistance box

was connected in series with the galvanometer and thermo-couple, and by means of this resistance, suitable sensitiveness was obtained.

Standardization of galvanometer (fig. 7). In order to be able to determine electromotive force by means of a galvanometer it was standardized by the "fall of potential" method, as follows:—

A primary circuit was made up of (1) a source of electromotive force (dry cell), (2) an adjustable resistance, *r* (3) a milliammeter. (4) a known resistance, *R*, such as a bridge wire, or standard ohm.

The terminals of the galvanometer circuit including the "adjusting resistance" *S* were connected across *R;* then for a given current *I* flowing around the primary circuit, the electromotive force acting on the galvanometer circuit is equal to $R \times I$.

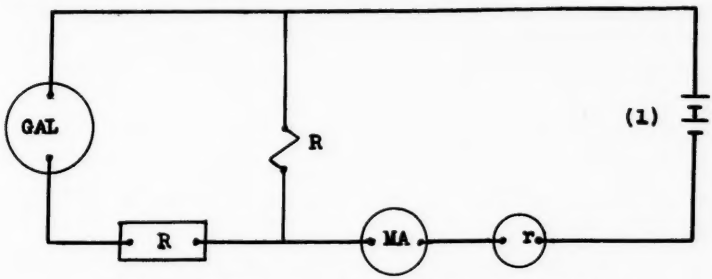


Fig. 7. Arrangement for standardizing galvanometer.

By adjusting *r* various values of *I* are obtained, hence various electromotive forces.

Results were recorded as follows:

(a) (b) (c) (d)

Amperes (M·A) Deflection (*G*) *EMF* [(a)$\times R$] Volts per mm. [(c)/(b)] (a) and (b) are obtained from readings of instruments *MA* and *G;* (c) is obtained by multiplying (a) by the resistance *R;* and (d) is found by dividing (c) and (b). Example: Resistance $R = .444$ ohm.

(a)	(b)	(c)	(d)
.00268	25mm.	.001189	.0000476

Now, the electromotive force of any thermo-couple acting is at once obtained by multiplying the deflection of the galvanometer by the factor (d).

Since the electromotive force of different couples varies widely, a number of values of S were used, and the galvanometer standardized for each one. The following values of S were used: 0, 350, 600, 2100, 5000, and 6000 ohms.

Method. The terminals of the thermo-couple were connected to the galvanometer, with the box S in series, as per fig. 9.

In order to insure that the only thermo-electric effects in the circuit were those to be measured, three junctions were used, *Cu*-M' (e); M'-M'' (f); and M''-*Cu* (g). The junctions (e) and (g) were maintained at 0°, and (f) was raised to various values of t By recording the temperature of (f), and the deflections of the galvanometer, the various electromotive forces of the circuit may be determined, and curves plotted.

Junctions (e) and (g) were placed in separate kerosene baths,

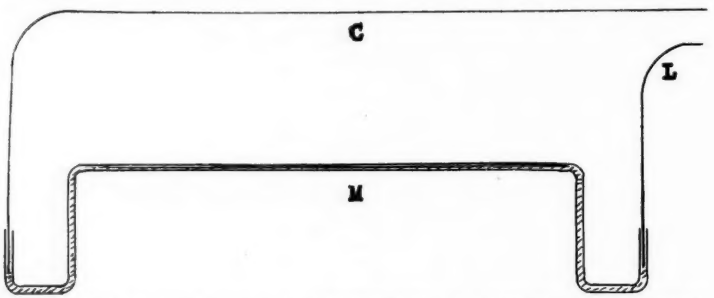


FIG. 8. C is a copper wire to the galvanometer; L, a lead wire, M, a glass tube containing mercury.

and these baths placed in the same ice-bath. This separation of the baths was effected to overcome any galvanic current that might be set up. Kerosene was used, since it does not corrode the metals.

Junction (f) was heated in a bath of heavy lubricating oil, which is non-corrosive, and is not volatile at the temperatures used.

In order to null thermo-effects at the various junctions (or rather connections) of the system, the junction (f) was first maintained at 0° by placing it in a third bath similar to those of (e) and (g), and "setting" the galvanometer at zero. These other thermo-effects were due to a number of causes, radiation from the body, from an incandescent lamp used for lighting the scale, etc.

Errors, which were afterward remedied, were introduced into the first few sets of readings taken, due to the following causes:

(a) The coil of the galvanometer was not hung in a uniform magnetic field, this was discovered in calibration.

(b) When the temperature was gradually raised, and after the flame had been removed, the deflection of the galvanometer would reach a maximum, and decrease, before the thermometer had reached its maximum. This "time drag" was due to the fact that glass, being a poor heat conductor, did not transmit heat to the mercury as rapidly as heat was transmitted to the couple.

(c) A great amount of trouble was encountered in getting a

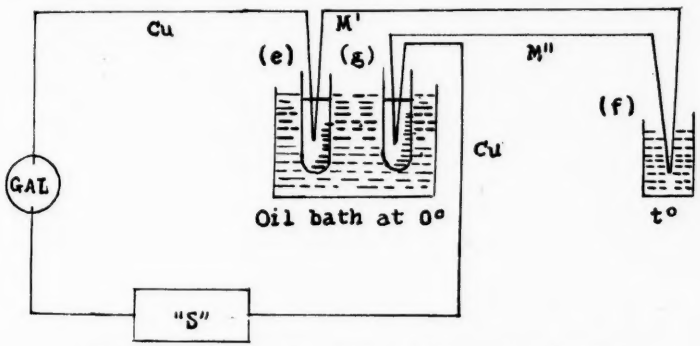


FIG. 9. Arrangement for measuring electromotive forces.

suitable method of joining the elements, *i. e.*, of producing the junctions themselves. The following methods were tried:

(1) Simple twisting. This scheme proved very satisfactory when the junction was wanted for immediate use; but after a few hours the results varied, due to corrosion, the metals oxidizing even where they were twisted the tightest.

(2) Soldering the wires. The use of solder in itself does not necessarily alter the thermo-electric effect, since from the law of intermediate metals, the electromotive force is not changed by the introduction of a third metal. But the flux necessary for soldering has a chemical effect whose thermo-electric characteristics are different. The presence of a mass of solder also tends to give a shunt across the junction, which permits the return of current.

(3) Fusing in an electric arc. By using a carbon block for cathode, and twisting the wires, then using the junction for anode, a current will melt the metals, and make an excellent junction. This scheme was finally resorted to for all the junctions except the *Pb-M* ones.

(4) For *Pb-M* junctions, a very satisfactory union was effected by melting the lead in a Bunsen flame, and joining the other metal in this way.

(5) In the case of the lead-mercury element, the *Hg* was contained in a tube of the form shown in fig. 8. The lead was cleaned, and inserted into the mercury in one end, and the copper line was inserted in the other end. Considerable caution had to be exercised to keep the lead from amalgamating, but by preparing a fresh specimen each time, this greatest difficulty was overcome.

Results of measurements of an advance lead thermo-couple (fig. 10). Current goes from Advance to lead in the hot junction. Junctions (e) and (g) at 0°; S = 5000 ohms, so (d) = .00004864 volts per mm.

(1) TEMPERATURE (f)	(2) DEFLECTION GALVANOMETER	(3) *EMF.*
0.0	0.0	.0000000
16.0	23.6	.0005275
35.0	32.1	.0011505
47.0	43.2	.0015665
73.0	51.4	.0025090
109.0	89.5	.0043550*
130.5	101.6	.0049500
141.0	108.6	.0052850
166.0	132.7	.0064500
183.2	147.8	.0072050
195.0	158.7	.0077300*
209.5	170.8	.0084100
221.2	189.9	.0092400
233.5	195.9	.0095400
243.3	206.6	.0100600
250.0	217.6	.0105800
262.0	230.8	.0112400
270.0	239.0	.0116400*
276.5	245.8	.0119600
283.0	252.2	.0122900
292.0	262.7	.0128300

Those readings marked with an asterisk were afterward checked by means of the potentiometer.

The resistance of this thermo-couple, with its copper leads was .74 ohm, so that, in comparison with the high resistance, S, it does not need to be taken into consideration.

Determination of the constants b and c.

(from the equation $E = bt + ct^2$)

$E_0^{35} = 35b + 1125c = .0011505$

also $E_0^{250} = 250b + 62500c = -.01058$

Solving these equations for b and c,

$b = 31.33 \times 10^{-6}$

$c = 4.39 \times 10^{-9}$

Advance manganin thermo-couple (fig. 11). Current goes from advance to manganin in the hot junction. Junctions (e) and (g) at 0. $S = 5000$ ohms. So (d) = .00004864 v.p. mm. Resistance of couple, and copper leads, .97 ohm.

(1) TEMPERATURE OF (f)	(2) DEFLECTION OF GALVANOMETER	(3) *EMF.*
0.0	0.0	.000000
17.0	12.2	.000596
26.5	19.0	.000927
80.0	63.2	.003076
126.0	99.1	.004821
143.0	113.1	.005520
163.5	130.4	.006360
188.3	152.0	.007210
199.5	163.1	.008000
225.0	189.2	.009220
241.0	205.9	.010020
258.5	224.3	.010930
269.0	235.5	.011460
278.0	245.6	.011980
287.0	258.2	.012600

$E_0^{80} = 80b + 6400c = .003075$

$E_0^{225} = 225b + 50825c = .009220$

From which equations,

$b = 29.65 \times 10^{-4}$

$c = 17.325 \times 10^{-9}$

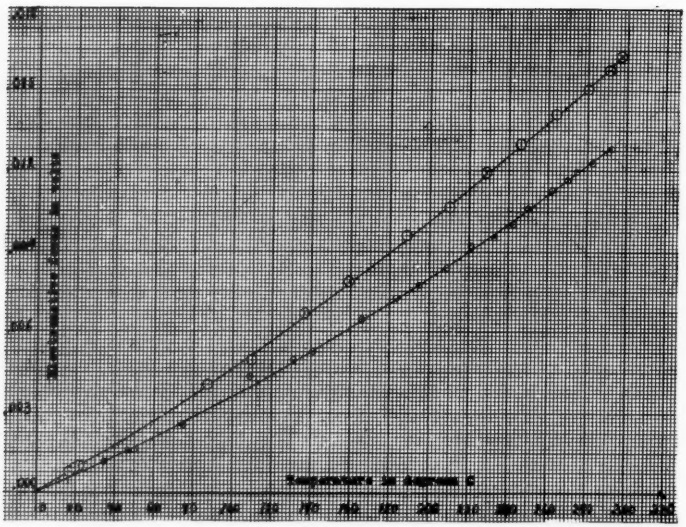


FIG 10. Upper curve, Advance-Iron junction: Lower curve, Advance-Lead.

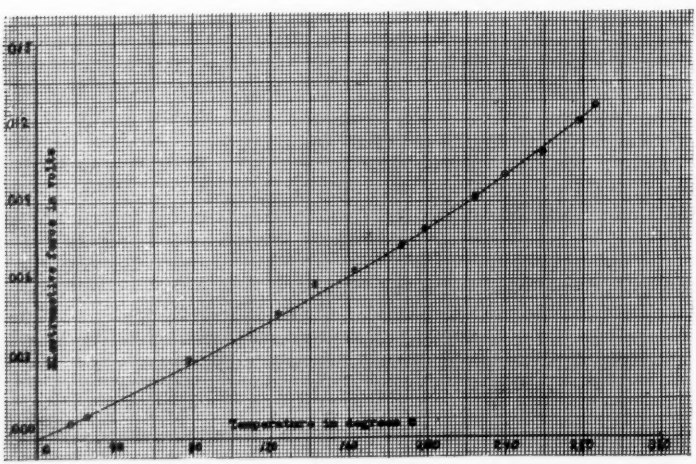


FIG. 11. Curve for Advance–Manganin Junction.

Advance iron thermo-couple (fig. 10). Resistance, .734 ohms. Current goes from advance to iron in the hot junction. Junctions (e) and (g) at 0. S = 6000 ohms. So (d) = .00006177 volts per mm.

(1)	(2)	(3)
0.0	0.0	.000000
17.0	12.6	.000780
19.8	14.1	.000872
22.0	16.3	.001008
87.7	65.6	.004050
111.0	80.6	.004970
137.0	108.5	.006690
159.2	127.7	.007890
188.7	155.8	.009610
210.0	175.7	.010680
229.1	193.5	.011970
246.5	210.6	.013000
265.4	229.7	.014170
280.6	244.6	.015070
291.0	254.6	.015770
297.0	261.4	.016160

From $E_0^{137} = 137b + 18769c = .00339$ and $E_0^{297} = 297b + 88209c = .01616$

$b = -6.4 \times 10^{-6}$

$c = 40.42 \times 10^{-8}$

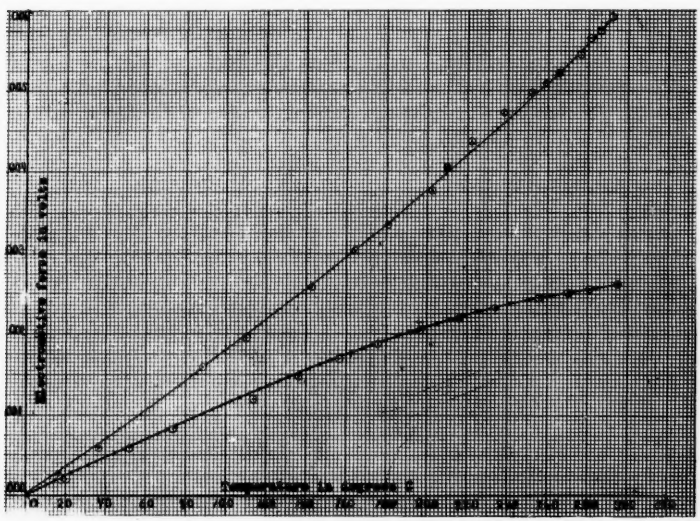


FIG. 12. Upper curve—Nickel-Lead Junction. Lower curve—Iron-Lead Junction.

Lead-Nickel couple (fig. 12). Resistance, .193 ohm. Current goes from Nickel to Lead in the hot junction. Junctions (e) and (g) at 0. S = 2100 ohms, so (d) = .00002383.

(1)	(2)	(3)
0.0	0.00	.0000000
17.6	10.37	.0002465
36.5	24.37	.0005805
88.7	68.67	.0016365
110.0	81.97	.0019515
143.2	109.57	.0025815
165.0	127.97	.0030465
181.0	141.57	.0033715
203.0	157.47	.0037565
210.0	170.17	.0040565
222.0	183.57	.0043765
238.0	198.37	.0047265
252.0	209.37	.0049965
259.0	214.50	.0051066
265.0	219.40	.0052461
276.0	228.50	.0054663
281.5	237.40	.0056565
286.0	241.20	.0057467
291.5	243.90	.0058215

Measurements of this junction by the potentiometer gave the following results: 110°, .0020137; 245°, .0049305.

Values of B and c taken from the readings at 110 and 252 degrees, are:

$b = -16.125 \times 10^{-6}$

$c = -14.69 \times 10^{-9}$

Iron Lead Couple (fig. 12). Resistance, .96 ohm. Current goes from lead to iron on the hot junction. $S = 599$ ohms. (The value of S + the resistance of the couple = 600 ohms). Junctions (e) and (g) at 0. Since res. = 600, (d) = .0000102814 v. per mm.

(1)	(2)	(3)
0.0	0.	.0000000
18.0	18.5	.0001900
20.5	19.0	.0001951
52.0	60.5	.0005975
74.0	85.1	.0008375
114.0	116.5	.0012000
137.0	144.0	.0014840
157.1	164.7	.0016940
176.0	181.3	.0018690
197.0	197.7	.0020350
216.0	211.2	.0021810
234.0	224.1	.0023100
256.0	237.7	.0024450
271.0	245.6	.0025300
281.0	250.8	.0025800
295.5	254.9	.0026250

$E_0^{18} = 18b + 324c = .00019$
$E_0^{216} = 216b + 46656c = .002181$ From which
$b = 10.787 \times 10^{-6}$
$c = 12.875 \times 10^{-9}$

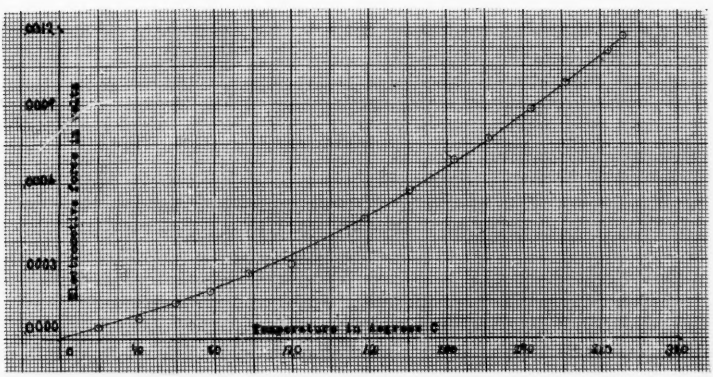


FIG. 13. Curve for Mercury-Lead Junction.

Mercury Lead couple (fig. 13). Current goes from mercury to lead in the hot junction. Junctions (e) and (g) at 0. $S = O$ so (d) = .000003133 v. per mm. *, $S = 350$ so (d) = .000005274 v. per mm.

(1)	(2)	(3)
0.0	0.0	.0000000
20.5	11.7	.0000367
41.5	27.0	.0000847
60.5	43.2	.0001352
78.5	60.7	.0001900
98.0	81.5	.0002555
120.0	92.0	.0002880
157.8	149.2	.0004675
182.8	185.0	.0005795
204.0	222.3	.0006980
222.5	147.0	.0007740
*244.0	169.8	.0008900
*262.9	189.0	.0009970
*282.0	214.3	.0011280
*292.0	224.8	.0011810

$E_0^{98} = 98b + 9604c = -.0002555$

$E_0^{244} = 244b + 59506c = -.0008900$ From which

$c = -71.33 \times 10^{-10}$

$b = -19.8 \times 10^{-7}$

Climax Lead couple (fig. 14). Resistance, 1.08 ohms. Current goes in the hot junction from the climax to the lead. S = 349 ohms, so that effective value of S = 350 ohms, so (d) = .000005274 v. per mm. Junctions (e) and (g) at 0°.

(1)	(2)	(3)
19.0	9.0	.0000475
67.0	30.0	.0001583
85.0	37.0	.0001955
113.0	48.0	.0002535
135.0	56.3	.0002976
150.0	62.0	.0003270
165.0	67.0	.0003540
178.0	71.8	.0003790
189.0	75.7	.0003990
203.0	80.0	.0004220
214.0	83.5	.0004410
221.0	85.5	.0004510
233.5	89.0	.0004690
241.0	90.8	.0004790
251.5	94.0	.0004960
263.5	97.2	.0005120
277.0	101.0	.0005320
287.0	103.1	.0005430
302.0	103.6	.0005450
305.5	106.0	.0005600

$E_0^{85} = 85b + 7225c = .0001955$
$E_0^{150} = 150b + 22500c = .0003270$ From which
$b = -14.8 \times 10^{-7}$
$c = 46.5 \times 10^{-10}$

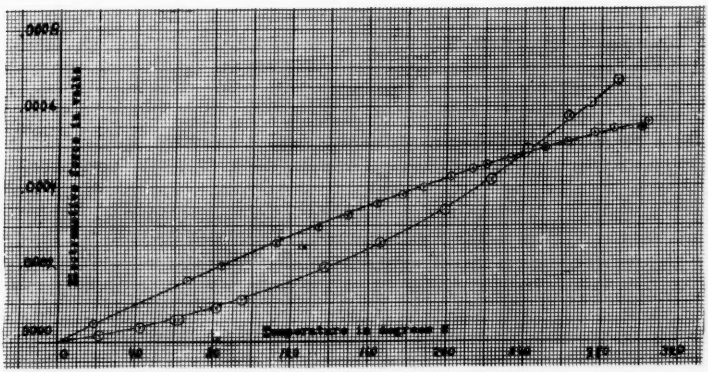


FIG. 14. Upper curve, Climax-Lead Junction. Lower curve, Lead-Manganin

Lead Copper couple (fig. 15). Resistance, .01 ohm. Current goes from lead to copper in the hot junction. Junctions (e) and (g) at 0. $S = 350$ ohms, so (d) = .000005274 v. per mm.

(1)	(2)	(3)
0.0	0.0	.0000000
21.0	9.6	.0000505
68.0	33.6	.0001777
100.0	53.0	.0002790
128.0	71.2	.0003750
145.0	83.2	.0004380
192.0	120.8	.0006370
220.0	144.0	.0007580
246.0	167.5	.0008810
254.0	175.0	.0009220
275.0	198.0	.0010410
299.0	222.0	.0011700
316.2	242.0	.0012730
260.0	183.0	.0009630
240.0	164.5	.0008670
149.0	89.0	.0004690

$E_0^{128} = 128b + 16384c = .000557$
$E_0^{243} = 243b + 59049c = .000491$ From which
$b = 1.2 \times (10)^{-7}$
$c = 13.58 \times (10)^{-9}$

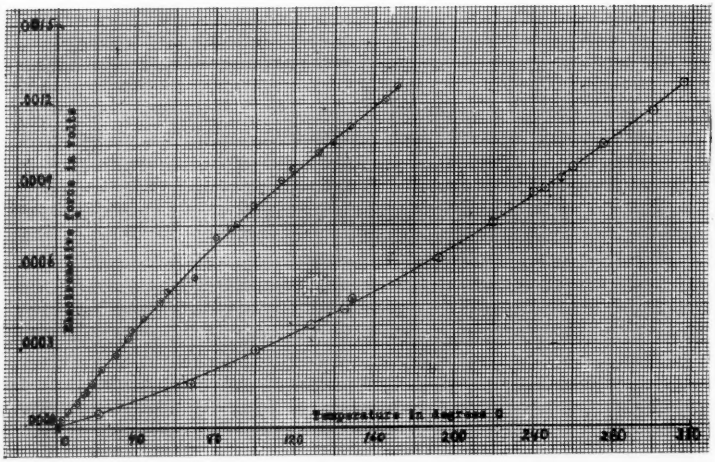


FIG. 15. Upper curve, Iron-Copper Junction. Lower curve, Copper-Lead.

Lead Manganin (fig. 14). $S = 0$. so (d) = .000003133—volts per mm. Junctions (e) and (g) at 0.

Current goes from lead to manganin in the hot junction.

(1)	(2)	(3)
0.0	0.0	.0000000
22.0	5.3	.0000166
43.0	11.7	.0000366
62.3	18.7	.0000587
82.0	27.1	.0000850
60.8	17.9	.0000560
95.0	33.2	.0001040
138.2	61.0	.0001910
167.0	82.5	.0002580
200.0	109.6	.0003420
224.0	133.0	.0004160
243.0	157.0	.0004910
266.0	184.0	.0005760
275.5	195.1	.0006100
289.0	213.2	.0006675

$E^{2} = 82b + 6724c = .000085$
$E^{000} = 200b + 40000c = .000342$ From which
$b = 1623.66 \times (10)^{-8}$
$c = 43.177 \times (10)^{-10}$

Iron Copper Thermo couple (fig. 15). Current goes from copper to iron in the hot junction. S = 4000 ohms, hence (d) = .0000308 volts per mm. (see below). Junctions (e) and (g) at 0.

(1)	(2)	(3)
0.0	0.00	.0000000
3.0	1.00	.0000308
5.8	2.00	.0000616
10.5	3.00	.0000924
13.5	4.10	.0001260
15.2	4.70	.0001445
18.3	5.30	.0001665
24.0	7.10	.0002180
29.6	8.90	.0002740
36.0	10.90	.0003350
38.3	11.80	.0003635
44.0	13.30	.0004090
51.0	15.00	.0004610
56.0	16.70	.0005130
60.0	18.10	.0005570
71.0	20.10	.0006090
80.0	22.90	.0007060
88.0	24.00	.0007400
89.3	24.60	.0007590
98.9	27.00	.0008310
113.7	30.00	.0009230
118.0	30.75	.0009480
132.0	33.50	.0010320
139.5	35.00	.0010780
148.3	36.50	.0011220
166.0	37.90	.0012210
171.85	40.60	.0012530

To determine the constants b and c
$E_0^{24} = 24b + 576c = .000218$
$E_0^{80} = 80b + 6400c = .000706$ From which
$b = 91.94 \times (10)^{-7}$
$c = 4.61 \times (10)^{-9}$

Standardization of Galvanometer. S = 4000 ohms.

(a) AMPERES	(b) DEFLECTION	(c) VOLTS	(d) V PER MM.
.0018	26.	.00080	.0000308
.00374	53.1	.00166	.0000312
.00536	75.9	.00238	.0000314
.00778	111.8	.00345	.0000313
.01021	145.5	.00453	.0000313
.01186	173.	.00529	.0000306
.01366	200.	.00609	.0000304
.0154	226.5	.00683	.0000303
.01694	250.	.00750	.0000300

Average = .0000308 volts per mm. of scale of galvanometer.

Construction of the thermo electric power diagram. As stated above, a very convenient method of determining the resultant electromotive force for any two metals at any temperatures consists in plotting the thermo electric power lines of these metals, with temperatures as abscissas, and "electromotive force in microvolts per one degree centigrade" as ordinates. After such a diagram has been constructed, all that it is necessary to do in order to find the electromotive force around a thermo-electric circuit of any metals, M and M', whose junctions are at t_1 and t_2 is to determine the area, with consideration of algebraic signs, enclosed in the quadrilateral composed of the two thermo-electric power lines of the metals, and lines drawn vertically at t_1 and t_2. This electromotive force is of course given in microvolts.

For convenience and simplicity, the lines of all metals are usually drawn upon one sheet, with the lead line, since lead does not show the Thomson effect, as the base line.

Now in drawing these lines, one has only to remember that b represents the ordinate at 0°, while $2c$ is the tangent of the angle between the thermoelectric power line, and the horizontal.

Thus in drawing the line for copper, "b" is equal to 1.2 microvolts, hence a point was located whose coördinates are (0, 1.2) Since "c" = .01358 microvolts, a point was located at 300° whose coördinates are (300, 9.26). The abscissa 9.26 was determined as follows: "c" was multiplied by $2t$ (= 2 × 300) and this result (8.06) was added to 1.2. Now by drawing a line connecting these two points, the thermo-electric power line for copper is complete.

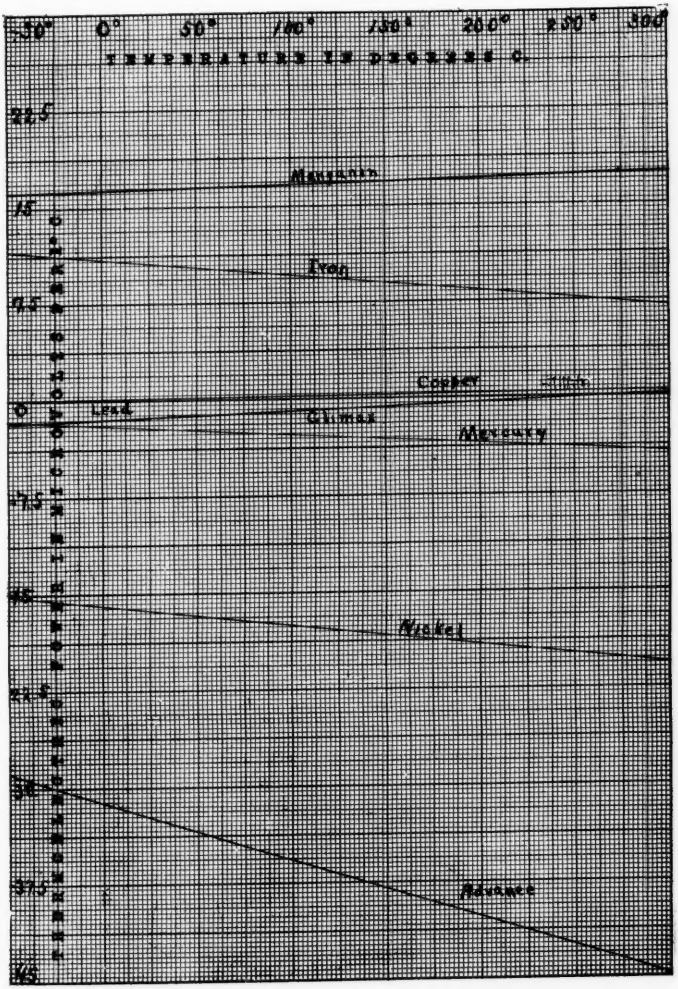


FIG. 16. Thermo-electric power diagram.

The thermo-electric power lines for the remaining metals were drawn in this same manner.

Conclusion. The preceding work was performed primarily with a view to investigating the thermo-electric characteristics of "advance," "climax," and "manganin" substances whose thermo-electric lines are not found on the text-book diagrams. The subsequent plotting of these lines is of no little interest. But as a check, the metals, nickel, mercury, iron, copper, whose lines are well known, were investigated, plotted, and the thermo-electric lines found to agree with existing diagrams within reasonable limits.

Barney Physical Laboratory.

THE MERCER LIMESTONE AND ITS ASSOCIATED ROCKS IN THE NEWARK-ZANESVILLE REGION[1]

CLARA GOULD MARK

CONDENSED HISTORICAL REVIEW

The Pottsville formation in Ohio consists of the following members, as given by Dr. Orton in the *Geological Survey of Ohio*, vol. vii, 1893, p. 36:

"Conglomerate group
Homewood sandstone
(Tionesta Coal)
Upper Mercer Group
Ore
Limestone
Coal, No. 3a, Newberry
Lower Mercer Group
Ore
Limestone
Coal, No. 3, Newberry
Massillon sandstone, upper
(Quakertown Coal), Coal No. 2, Newberry
Massillon sandstone, lower
Sharon Coal–Coal No. 1, Newberry
Sharon Conglomerate."

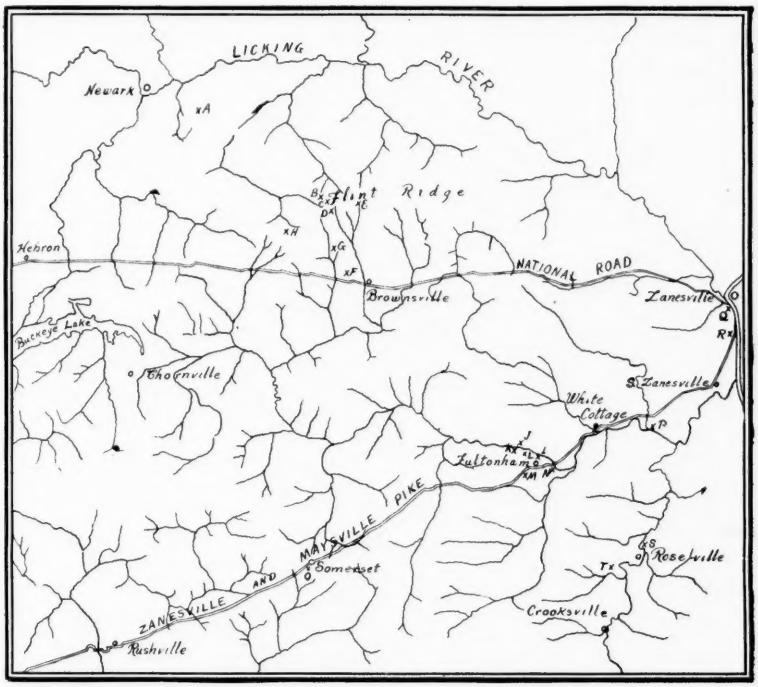
The limestone of the Lower Mercer Group is usually referred to as the Mercer limestone, the name having been first applied to it in 1858 by H. D. Rogers from its exposures in Mercer County, Pennsylvania (*Geology of Pennsylvania*, vol. ii, pt. 1, 1858, p. 476). The occurrence of this limestone in Ohio was mentioned

[1] This paper is part of a thesis presented for the degree of Master of Arts in the Ohio State University. The work was done under the direction of Dr. Charles S. Prosser to whom I am greatly indebted for his kind assistance and advice.

by Charles Briggs, Jr., in the *First Annual Report* of the Geological Survey of Ohio, published in 1838. In the *Second Annual Report,* published later in the same year, Col. J. W. Foster described exposures of the Mercer limestone in Muskingum and Licking counties. Neither Mr. Briggs nor Col. Foster gave any name to the limestone, but referred to it merely as "blue limestone."

In the *Report of Progress in 1869* published in 1870, Professor E. B. Andrews described the occurrence of the Mercer limestone in Muskingum, Licking, Perry and Hocking counties, but owing to an unfortunate mistake in identification by one of his assistants, he called it, with but one exception, the "Putnam Hill limestone." This one exception is in the description of the section at Putnam Hill where the limestone in the bed of the Muskingum is said to be possibly the same as the Maxville (p. 84). In the *Report of Progress in 1870* published in 1871, Professor Andrews continued tracing the line of the Mercer limestone from Hocking County through Vinton, Jackson and Scioto counties to the Ohio River, still calling it the "Putnam Hill limestone" though at times referring to it as the "Blue limestone." In the same volume is an account by Dr. Newberry of exposures of the Mercer limestone and Coal No. 3 which underlies it, in various localities from Coshocton County east to the Pennsylvania line.

Professor Andrews in volume i of the *Geological Survey of Ohio* (1873, p. 317) calls attention to the mistaken use of the name "Putnam Hill" for the Mercer limestone, and gives the correct stratigraphical position of the Maxville, Mercer, and Putnam Hill limestones in Muskingum County. He does not give any name to the Mercer limestone, but describes it as a limestone intermediate in position between the Maxville and Putnam Hill. In volume ii of the *Geological Survey of Ohio,* 1874, pp. 81–180, Dr. Newberry refers to the Mercer limestone a number of times as the "Zoar limestone," but does not give any detailed description of it. Dr. Orton was the first to give a careful description of it under this name (vol. iii, 1878, p. 891). In this account he says that the "Zoar limestone" is the best marked stratum in the Lower Coal Measures of the State, and that it may be followed from the Pennsylvania line across Ohio to the Ohio River. In the Report



A Bald Knob
B Flint Ridge Cannel Coal Mine
C Four-corners near Cannel Coal Mine
D Limestone Hollow
E Flint Ridge Four-corners
F Buzzard Glory Knob
G Fairview Knob
H Oil well on the Logan Stevens Farm
I Hough's Hollow
J Stonehouse Hollow
K Wortman's Ravine
L The Roberts Ravine
M The Allen Coal Entry
N Fultonham Brickyard
O Railroad Cut at Somerset
P Elizabeth
Q Putnam Hill
R The Weller Pottery, Putnam
S Roseville Brickyard
T Oil well on the David Allen Farm

FIG. 1. Sketch map of the Newark-Zanesville region.

of the *Geological Survey of Ohio*, vol. v, 1884, pp. 13 and 14, Dr. Orton correlates this limestone with the Lower Mercer of Pennsylvania and describes it at some length.

DESCRIPTION OF LOCAL SECTIONS

The region studied in the preparation of this paper extends from the vicinity of Newark, Ohio, east to Zanesville and south to Somerset and Roseville, and embraces portions of Licking, Muskingum and Perry counties. Particular attention was given to the Mercer limestone as it occurs in this area, and where opportunity afforded the associated rocks both above and below it were also studied to some extent. In the various exposures studied the strata were seen in ascending order from the Maxville limestone at the top of the Mississippian system, through the entire thickness of the Pottsville formation at the base of the Pennsylvanian system, and up to the Lower Kittanning coal in the Allegheny formation.

NEWARK

Bald Knob. Near Newark the Pottsville is the highest formation exposed, and the Mercer limestone is its highest member seen in this vicinity, being found only upon the top of one of the highest hills. This hill, spoken of in the various Ohio reports as Bald Hill, McFarland's Hill, and "the hill above Dr. Wilson's old coal entry," lies about two miles southeast of Newark, and on the topographic map of the United States Geological Survey is called Bald Knob. The crest of the hill is 1220 feet above sea level, and about 400 feet above the level of the South Fork of the Licking River at the Second Avenue Bridge. The following section was measured here:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
5. *Mercer limestone.* The top of the hill is covered with broken blocks of dark blue very fossiliferous limestone which weathers into somewhat shaly fragments. None of the limestone is in place, and the heaviest block seen measured 8 inches in thickness. A small proportion of these fragments are less shaly and when weathered are buff in color and much lighter in weight than the shaly dark blue limestone. They are extremely fossiliferous, but the fossils are, as a rule, not so well preserved as in the blue limestone.		187½
4. Covered to the horizon of the Sharon coal. One hundred feet by barometer below the top of the hill are the remains of "ore diggings" on the eastern side of the hill, where ore has been worked by stripping. Ore is said to have been taken out here about 1850 and shipped to Mary Ann Furnace on the north side of the Licking river in Mary Ann township.	125½	187½
3. *Sharon coal (?).* There is an old coal entry near the house on the west side of the hill. The thickness of this coal is given by M. C. Read in his account of the geology of Licking county as 30 inches. On the north side of the hill are more recent entries where the coal is reported to be 27 inches thick. The coal has not been worked for a number of years and all the openings have fallen in, and there is some uncertainty as to whether they are all in the Sharon horizon.	2½	62
2. Covered interval.	48	59½
1. *Sharon conglomerate.* Coarse-grained quartzose sandstone with layers of conglomerate; light buffy colored, but much of it iron stained and weathered red or red-brown. The pebbles in the conglomerate are small, most of them less than one-fourth inch in diameter, generally but not all white quartz, and cemented rather loosely, so that when the rock is broken the pebbles along the fracture are loosened from the matrix instead of breaking. Base of the Pottsville formation.	11½	11½

The following fossils were collected from the limestone on top of the hill:

Septopora rectistyla Whitfield

Orbiculoidea convexa (Shumard)
Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spiriferina kentuckiensis (Shumard)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Edmondia ovata Meek and Worthen
Edmondia nebrascensis Geinitz
Nucula beyrichi von Schauroth?
Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Parallelodon sangamonensis
Myalina swallovi McChesney
Aviculopecten coxanus Meek and Worthen
Aviculopecten occidentalis (Shumard)
Aviculopecten herzeri Meek
Acanthopecten carboniferus (Stevens)
Euchondria neglecta Geinitz
Pecten (Entolium) aviculatus (Swallow)
Lima retifera Shumard
Allorisma terminale Hall
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek
Cypricardinia carbonaria Meek
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Bucanopsis montfortiana Norwood and Pratten
Euomphalus catilloides Conrad

Phillipsia major Shumard.

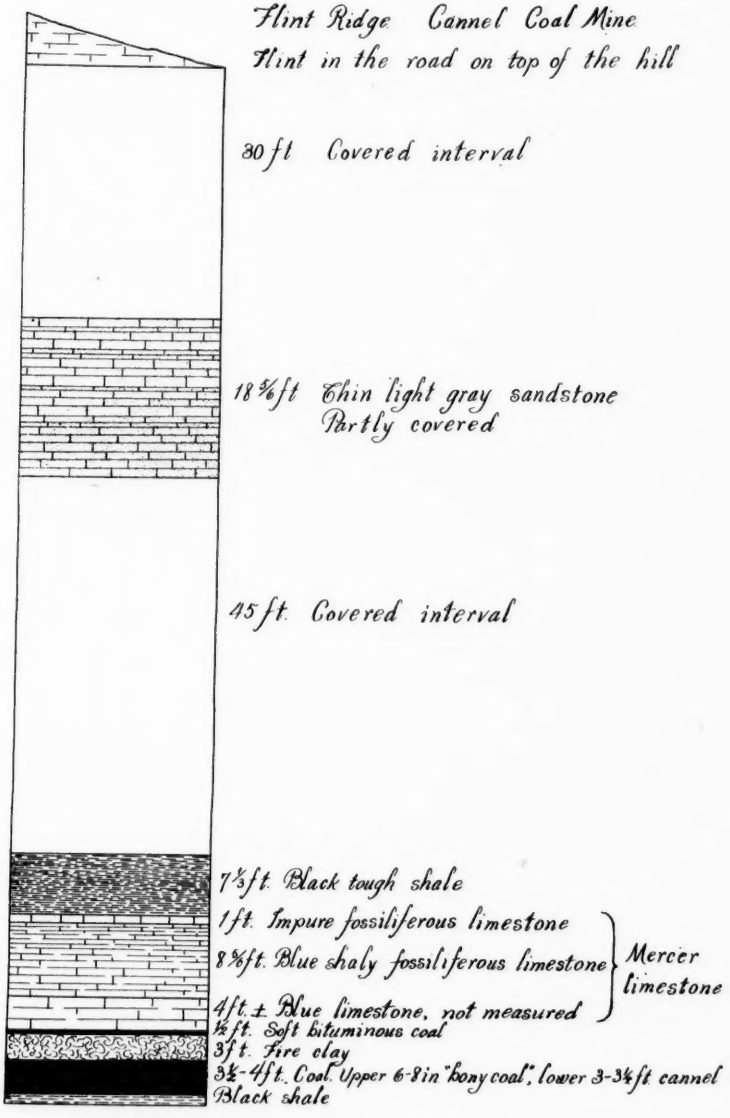

Flint Ridge Cannel Coal Mine
Flint in the road on top of the hill
80 ft Covered interval
18 ⅚ ft Thin light gray sandstone
Partly covered
45 ft. Covered interval
7 ⅓ ft. Black tough shale
1 ft. Impure fossiliferous limestone
8 ⅚ ft. Blue shaly fossiliferous limestone
4 ft. ± Blue limestone, not measured
Mercer limestone
½ ft. Soft bituminous coal
3 ft. Fire clay
3½-4 ft. Coal. Upper 6-8 in "bony coal", lower 3-3¼ ft cannel
Black shale

FIG. 2. Section at the Flint Ridge Cannel Coal Mine.

A quarter of a mile south of Bald Knob where the highway crosses the hill at a slightly lower elevation, the Mercer limestone may be seen in the road, apparently in place. No fossils were collected here.

By the side of the road north of Bald Knob is a large block of Mercer limestone that has evidently slipped down from its original position. This had a thickness of two feet. The following fossils were collected from this block:

Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus longispinus Sowerby
Spiriferina kentuckiensis (Shumard)
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Parallelodon tenuistriatus Meek and Worthen
Schizodus cuneatus Meek
Aviculopecten coxanus Meek and Worthen
Aviculopecten cf. *fasciculatus* Keyes
Acanthopecten carboniferus (Stevens)
Pecten (Entolium) aviculatus (Swallow)
Lima retifera Shumard
Allorisma terminale Hall
Pleurophorus subcostatus Meek and Worthen
Astartella newberryi Meek

FLINT RIDGE

In the southeastern part of Licking county and extending eastward into the western part of Muskingum is a well defined ridge with numerous spurs and outliers, which rises at its western extremity to an elevation of more than 1200 feet above sea level. Eastward its elevation is somewhat less, though it is still more than 1100 feet at the Licking-Muskingum county line; and for a distance of eight miles or more this ridge forms the dominant topographic feature of the region. The locality attracted the attention of the early settlers, and received its name, by reason of the extensive deposit of flint upon the highest parts of the hills.

FIG. 3. *A*. Mercer limestone in Limestone Hollow, Flint Ridge, showing lower massive and middle shaly zone. *B*. Mercer limestone in Limestone Hollow, Flint Ridge, showing lower massive, middle shaly, and upper impure zones.

The flint is not seen in a continuous ledge or at a definite horizon on the hills, but is scattered over all the higher parts of the ridge in masses ranging in size from large blocks weighing many tons to the most minute fragments. This mantle of flint was aptly described in one of the early Ohio reports as lying "like a blanket" over the ridge. It is no doubt owing to this protecting mantle that the Flint Ridge region has been able to resist erosion better and to maintain a greater elevation than the surrounding country.

During the early part of the last century the flint was of considerable economic value to the inhabitants of this part of the state, as it furnished material from which they manufactured millstones or "buhrs." These millstones, while not considered equal to the best imported ones, still furnished an acceptable substitute for them at a time when importation was difficult, and many of the early mills of southeastern Ohio are said to have been supplied with millstones made of flint from Flint Ridge. This was not, however, the first use made of the flint. Numerous excavations along the summit of the ridge, made before the coming of white men into this region, give evidence that the flint was extensively worked by earlier inhabitants of the country, and the many flint darts and spear heads that have been picked up along the ridge and in the surrounding region indicate the principal use made of it. It is supposed that the Indians mined the flint, after first clearing away the protecting soil, by building on the surface of the solid flint large fires so that the underlying rock became very hot, and then throwing water on it, causing it to shatter. This process was repeated until blocks of fresh flint of a workable size could be obtained, the flint which had been protected by several feet of soil being much more easily worked than that which had been exposed to the weather for some time. There are said to be along the length of the ridge over eleven hundred of the pits left by this process of mining, the largest one being more than eighty feet in diameter and said to penetrate the Lower Mercer coal. Gerard Fowke, in his *Archaeological History of Ohio*, 1902, p. 624, says: "Evidently aboriginal excavations at Flint Ridge extended over a long period; for the material is found in the largest

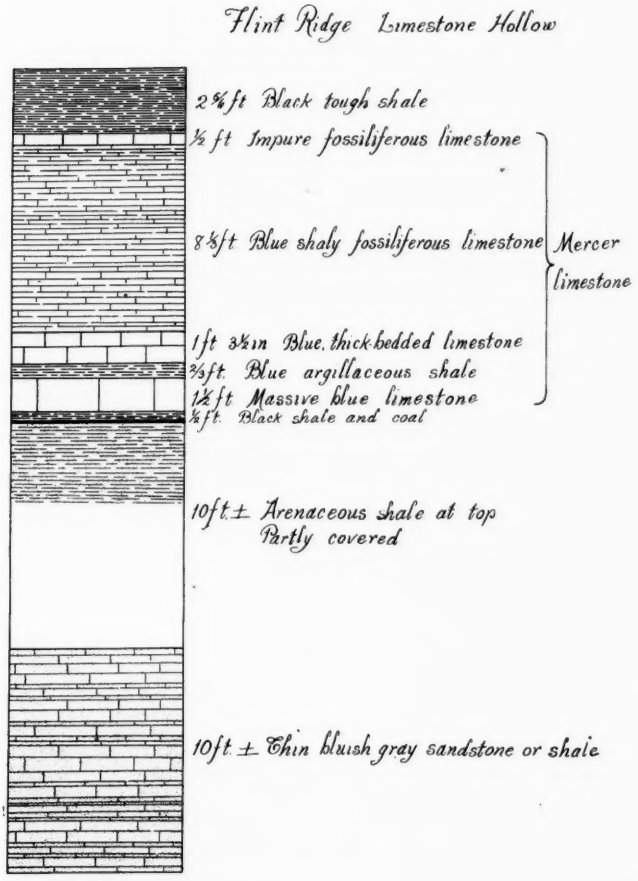

Flint Ridge Limestone Hollow
2 ½ ft Black tough shale
½ ft Impure fossiliferous limestone
8 ½ ft Blue shaly fossiliferous limestone
Mercer limestone
1 ft 3 ½ in Blue, thick-bedded limestone
⅔ ft Blue argillaceous shale
1 ½ ft Massive blue limestone
½ ft Black shale and coal
10 ft ± Arenaceous shale at top
Partly covered
10 ft ± Thin bluish gray sandstone or shale

FIG. 4. Section in Limestone Hollow, Flint Ridge.

mounds explored in the Kanawha, Scioto and Miami valleys, as well as on the sites of modern villages."

In appearance the flint is quite attractive, fresh specimens being as a rule more or less translucent and exhibiting a range of colors varying from pure white through different shades of yellowish brown, red, purple, and blue, to black. When weathered it seems to become less translucent and often has a tendency to break up into small rectangular pieces. The flint contains numerous cavities which are usually lined, and sometimes completely filled, with druses of quartz crystals. Many of these crystals are large enough so that their crystalline form may be readily seen without the aid of a magnifier, while others are so small that they merely impart a frost-like appearance to the surfaces they cover. When carefully examined they appear to be almost colorless in themselves but they often borrow the color of the underlying flint and show beautiful shades of blue, amethyst, red, brown and yellow.

The more impure portions of the flint very frequently contain large numbers of small foraminifera of the species *Fusulina secalica*. In some places the rock is completely filled with these fossils, and as many as one hundred and fifty have been counted in a single square inch. The flint containing the *Fusulinas* is usually white or light buff in color, and does not show the more brilliant colors of the purer flint. The quartz crystals, however, are abundant, often being intermingled with the fossils. The flint of this character is said by Mr. Fowke to be found upon the borders of the flint area, while that which is purer, more compact and brighter colored occupies the central portion. On page 622 of the *Archeaological History of Ohio* he gives an account of the clearing out of one of the pits at Flint Ridge, in which was found forty inches of flint resting directly upon solid blue limestone.

It seems quite probable that the flint and underlying limestone represent the horizon of the Putnam Hill limestone, though more extensive field work will be necessary before such a correlation can be made with any degree of certainty.

Flint Ridge Cannel Coal Mine. Just north of the west end of Flint Ridge is a bed of cannel coal which has been mined in a small way for the last seventy years or more. At present coal is being

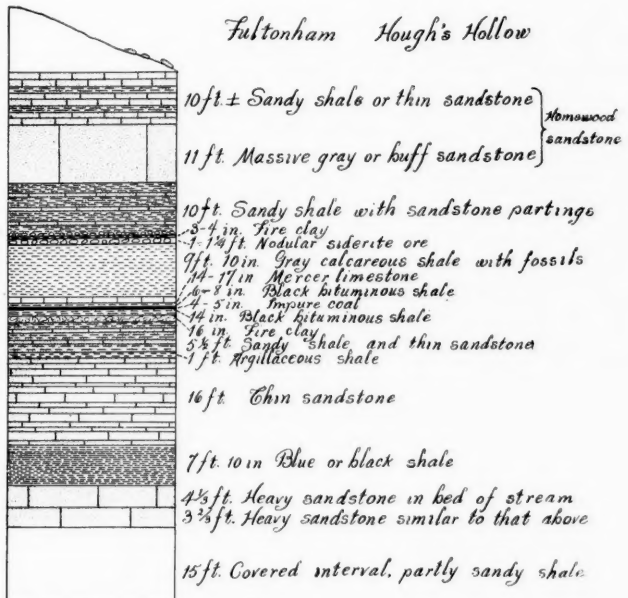

Fultonham
Hough's Hollow
10 ft ± Sandy shale or thin sandstone
11 ft. Massive gray or buff sandstone
Homewood sandstone
10 ft. Sandy shale with sandstone partings
3-4 in. Fire clay
1-1½ ft. Nodular siderite ore
9 ft. 10 in. Gray calcareous shale with fossils
14-17 in Mercer limestone
6-8 in. Black bituminous shale
4-5 in. Impure coal
14 in. Black bituminous shale
16 in. Fire clay
3½ ft. Sandy shale and thin sandstone
1 ft. Argillaceous shale
16 ft. Thin sandstone
7 ft. 10 in Blue or black shale
4⅓ ft. Heavy sandstone in bed of stream
3⅓ ft. Heavy sandstone similar to that above
15 ft. Covered interval, partly sandy shale
5 ft. Thin, dark colored sandy shale
7½ ft. Thin grayish blue shale
4 ft. Black bituminous shale, coaly at top (Wellston?)
2¾ ft. Gray argillaceous shale or clay
3 ft. Soft blue or black argillaceous shale
3⅔ ft. Covered. Traces of coal in bed of stream
4⅓ ft. Heavy buff sandstone Sharon conglomerate
10¾ ft. Sandy shale with partings of sandstone
8⅓ ft. Thick bedded gray or bluish limestone
2 3½ ft. Thin bedded limestone, shaly partings
Maxville limestone
3 ft. Covered to the level of Jonathan creek

FIG. 5. Section in Hough's Hollow, Fultonham.

taken from Mr. Wm. Jones' drift which is just north of the Flint Ridge road, and about one-quarter of a mile from the western boundary of Hopewell township. The following section was measured at this place, leveled from an old coal drift a few rods northwest of the Wm. Jones drift:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
13. Flint in the road at the west end of the ridge in the edge of the woods.		
12. Covered interval.	30	122½
11. Light gray to white coarse-grained, micaceous sandstone, friable and largely quartz. Partly covered.	18⅚	92½
10. Covered interval.	45	73⅔
9. Black tough shale, no fossils seen.	7⅓	28⅔
8. Top of *Mercer Limestone*. A layer of impure dark gray or bluish gray limestone containing many fossils, but the majority of them poorly preserved and fragmentary. When the rock is weathered the lime leaches out, leaving the rock buff or brown in color and much lighter in weight.	1	21⅓
7. Blue or bluish black limestone, fossils abundant and well preserved. In fresh exposures the limestone consists of massive layers with shaly partings. The upper layer of limestone is 1¾ feet thick. When weathered the limestone becomes shaly and is easily split up, and the fossils are readily obtained.	8⅝	20⅓
6. The lower part of the limestone and the underlying coal could not be measured at this drift, but there appears to be about four feet more of the limestone before the coal horizon is reached.	4±	11½
5. Soft coal, bituminous and with slickensides. Wm. Jones' coal drift.	½	7½
4. Fire clay containing a considerable amount of sand; heavy and hard on fresh exposure, but soon weathers soft and falls. In many places this shows slickensides.	3	7
3. "Bony" coal.	½±	4
2. Cannel coal with conchoidal fracture. This is said by one of the miners to thin toward the west to two feet and to thicken toward the east to six feet.	3-3½	3½
1. Black shale with *Lingula tighti* Herrick.		

A quantity of the limestone was taken out of this old drift two or three years ago in order to ascertain the exact horizon of the coal when the new entry was made, and from this material the following collection was made:

Fenestella shumardi Prout

Glossina waverlyensis Herrick
Orbiculoidea convexa (Shumard)
Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spiriferina kentuckiensis (Shumard)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Solenomya radiata Meek and Worthen
Solenomya anodontoides Meek
Prothyris elegans Meek
Edmondia cf. *aspinwallensis* Meek
Edmondia ovata Meek and Worthen
Edmondia reflexa Meek
Nucula parva McChesney
Leda bellistriata Stevens
Yoldia stevensoni Meek
Parallelodon carbonarius Cox
Parallelodon obsoletus Meek
Avicula ohioense Herrick
Schizodus cuneatus Meek
Schizodus curtus Meek and Worthen
Schizodus wheeleri Swallow
Aviculopecten coxanus Meek and Worthen
Aviculopecten occidentalis Shumard
Aviculopecten herzeri Meek
Acanthopecten carboniferus Stevens
Pecten (Entolium) aviculatus (Swallow)

Entolium attenuatum Herrick
Lima retifera Shumard
Placunopsis carbonaria Meek and Worthen
Allorisma terminale Hall
Allorisma sp.
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek
Pleurophorus subcostatus Meek and Worthen
Cypricardinia carbonaria Meek
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Euphemus carbonarius (Cox)
Bucanopsis marcouana Geinitz
Bucanopsis montfortiana Norwood and Pratten
Pleurotomaria broadheadi White
Bulimorpha inornata Meek and Worthen
Soleniscus klipparti Meek

Conularia sp.

Orthoceras sp.
Nautilus sp.

Phillipsia major Shumard

At the four corners to the southeast of the coal drift is an exposure of sandstone supposed to be the Homewood, and a short distance from this, down the hill to the north the Mercer limestone is exposed in an old coal drift just below the highway. The section here is as follows:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
4. Flint in the road near the top of the hill east of the four corners.		
3. Covered interval.	42	132⅓
2. *Homewood sandstone.* Exposed in the gutter and at the side of the highway.	21	90⅓
1. Interval from the base of the Homewood sandstone as seen, to the base of the Mercer limestone.	69⅓	69⅓

The following fossils were collected from the Mercer limestone at this old coal drift:

Fenestella shumardi Prout

Orbiculoidea convexa (Shumard)
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Aviculopecten herzeri Meek
Acanthopecten carboniferus (Stevens)
Pecten (*Entolium*) *aviculatus* (Swallow)
Entolium attenuatum Herrick
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Bellerophon percarinatus Conrad
Euphemus carbonarius (Cox)
Bucanopsis marcouana Geinitz
Bucanopsis montfortiana Norwood and Pratten

Crinoid segments

Limestone Hollow. About three-quarters of a mile southeast of the cannel coal mine and just east of the road that leads south past the Fairview School, is a gully called Limestone Hollow where the entire thickness of the Mercer limestone may be seen. The section measured here is as follows:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
9. Black, rather tough shale which splits into rather thin laminae. Fossils scarce.	$2\frac{5}{6}$	$35\frac{2}{3}$
8. Top of *Mercer limestone.* One stratum of the impure limestone similar to that at the top of the Mercer at the cannel coal mine.	$\frac{1}{2}$	$32\frac{5}{6}$
7. Dark blue limestone which splits into rather shaly pieces with sharp edges; very fossiliferous, especially the upper part. Eight inches below the top is a very abundant *Productus cora* zone about one inch thick.	$8\frac{1}{3}$	$32\frac{1}{3}$
6. Blue, rather irregular, but fairly thick-bedded limestone.	$1\frac{1}{3}$	24
5. Bluish argillaceous shale.	$\frac{2}{3}$	$22\frac{2}{3}$
4. Massive blue limestone, not very fossiliferous. Base of *Mercer limestone.*	$1\frac{1}{2}$	22
3. Black shale and coal; only the top of the coal shown.	$\frac{1}{2}\pm$	$22\frac{1}{2}$
2. Partly covered. Bluish gray coarse arenaceous shales at top.	$10\pm$	20
1. Thin sandstones to arenaceous shales, bluish gray in color.	$10\pm$	10

The following species of fossils were obtained at this locality:

Fenestella shumardi Prout
Septopora biserialis Swallow

Glossina waverlyensis Herrick
Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spiriferina kentuckiensis (Shumard)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Solenomya anodontoides Meek
Edmondia reflexa Meek

Edmondia nebrascensis Geinitz
Leda bellistriata Stevens
Yoldia stevensoni Meek
Parallelodon carbonarius Cox
Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Schizodus cuneatus Meek
Schizodus curtus Meek and Worthen
Aviculopecten coxanus Meek and Worthen
Aviculopecten occidentalis (Shumard)
Aviculopecten cf. *fasciculatus* Keyes
Acanthopecten carboniferus (Stevens)
Pecten (*Entolium*) *aviculatus* (Swallow)
Lima retifera Shumard
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek
Pleurophorus subcostatus Meek and Worthen
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Bellerophon crassus Meek and Worthen
Bellerophon percarinatus Conrad
Euphemus carbonarius (Cox)
Bucanopsis montfortiana Norwood and Pratten
Soleniscus klipparti Meek

Phillipsia trinucleata Herrick

Crinoid segments

Flint Ridge Four Corners. A little more than a mile east of the four corners near the coal drift another road from the north crosses the Flint Ridge road at what is known as Flint Ridge Four Corners. Just south of here on the road toward Brownsville a large block of flint may be seen at the side of the highway, and somewhat farther south the Mercer limestone is shown in the gutter. The following section was measured:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
8. Fairly pure, bluish white flint, showing some other colors, and with numerous cavities filled with quartz crystals.	5±	99½
7. Impure porous limestone weathering to a buff color, and containing many cavities filled with clay; somewhat shaly toward the bottom. The limestone contains some fossils, *Fusulina secalica, Chonetes mesolobus* N. & P., and *Reticularia perplexa* (McChesney).	3½+	94½
6. Calcareous shale.	1	91
5. Covered interval.	40	90
4. *Homewood sandstone.* Thin-bedded, bluish gray, micaceous sandstone, composed largely of quartz grains.	40	50
3. Thin black shale, no fossils seen.	4±	10
2. *Mercer limestone.* The deposit of limestone at this place is thinner than in the other exposures, but it presents the same lithological characters and carries the same fauna.	4½-5	6
1. Fire clay.	1±	1

About a quarter of a mile northeast of Flint Ridge Four Corners a ledge of flint is shown apparently in place at the head of a small gully. The flint on one side of the gully measured ten feet at its thickest place, while the greatest thickness of that on the other side was seven feet and three inches.

Buzzard Glory Knob. Two and one-half miles south of Flint Ridge, and just north of the National Pike west of Brownsville, is a high hill to which the name Buzzard Glory Knob is given on the topographic map, and which is locally called Benny Iden's Hill. The top of this hill is composed of an impure argillaceous limestone which lithologically resembles the limestone below the flint near the Flint Ridge Four Corners. There are a good many rather small blocks of flint scattered over the top of the hill, apparently the remnant of the flint limestone with which it was formerly capped. Specimens of *Fusulina secalica* are found in some of these blocks. The impure limestone contains a considerable number of fossils, and the following species were collected, *Chonetes mesolobus* being most abundant:

Fusulina secalica (Say)
Fenestella shumardi Prout
Septopora biserialis Swallow

Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Productus punctatus (Martin)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Fairview Knob. This hill is a mile and a half from Buzzard Glory Knob, a little west of north, and the road from the Flint Ridge coal mine to the National Pike crosses the hill not far below its highest point. The hill is capped by the flint, and on its southern slope the Mercer limestone and several ledges of sandstone may be seen in the road. The following measurements were made:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
6. Flint ledge on the top of the hill.		
5. Interval to the top of the Mercer limestone shown along the highway. Immediately below the flint on the top of the hill is seen impure argillaceous limestone, the same as that observed on Buzzard Glory Knob. Farther down the hill some blocks of sandstone are shown in the road near its highest point. These are not well shown, but they are evidently Homewood sandstone.	76	214
4. *Mercer limestone.*	8	138
3. Interval to ledge of coarse-grained sandstone in the road.	10	130
2. Interval to ledge of coarse-grained sandstone.	60	120
1. Interval to lowest ledge of sandstone in the road. This is coarse-grained quartz sandstone, probably the Sharon.	60	60

North of this hill 13 feet of the Mercer limestone is shown along the highway, its base being about 110 feet below the flint on top of the hill. A coal drift in the field to the west is apparently at the same level as the base of the Mercer.

The top of Fairview Knob is fairly well covered with masses of flint, but the underlying impure limestone was found in woodchuck burrows almost to the top, which indicates that only the lower part of the flint is left. This impure limestone contains numerous irregular cavities out of which clay-like masses have weathered. In the blocks not weathered so much the clay fillings were found. The limestone contains the same fossils as those collected on Buzzard Glory Knob.

The Logan Stevens Farm. On this farm, a mile and a half west of Fairview Knob, a well was drilled for oil in the summer of 1908. A large amount of the flint is shown in the road on the ridge just east of this well, and in the lane near Mr. Stevens' house the Homewood sandstone is exposed. According to the barometer this exposure of Homewood sandstone is 45 feet below the flint on top of the ridge, and the derrick floor at the oil well is 110 feet lower than the sandstone. The Mercer limestone on the Flint Ridge road to the north is 75 feet higher than the derrick floor, or 35 feet lower than the sandstone. The following record was obtained from one of the well drillers:

	Feet
8-inch drive pipe	119
Berea Grit sand, top	850
Berea Grit sand, bottom	865
$6\frac{5}{8}$-inch casing	870
Niagara Lime, top	1820
Heavy flow of water at 2500 feet, hole filled up 1800 feet.	
Niagara Lime, bottom	2720
$5\frac{3}{16}$-inch casing	2720
Clinton Sand, top	2888
Light show of oil.	
Clinton Sand, bottom	2932
Total depth	2971

The "Niagara Lime" of this record no doubt includes the Devonian and Monroe limestones as well.

FULTONHAM

Hough's Hollow. At Fultonham in the southwestern corner of Muskingum county there are numerous exposures of the Mercer limestone, which is well shown here in its relation to the underlying rocks. Several of these exposures were studied and sections measured, the first one being in Hough's Hollow, a ravine directly north of the village.

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
30. The upper one hundred feet or so of the hills is covered, but toward the base of this covered portion rather large broken blocks of coarse sandstone are scattered over the hillside. These blocks are weathered black on the outside, but fresh fractures show a rather dark brown color. Fragments of Lepidodendron are commonly found.	100±	255 5/12
29. *Homewood sandstone.* Gray or buff sandy shales or thin micaceous sandstone.	10±	155 5/12
28. Massive gray or buff sandstone composed mostly of quartz grains. Base of *Homewood sandstone.*	11	145 5/12
27. Light colored arenaceous shale with sandstone partings. The sandstone layers are closer and heavier toward the top and are similar in appearance to the massive sandstone above. At the base of the shale is an horizon of ore nodules.	10	134 5/12
26. Fire clay.	1/3	124 5/12
25. Siderite ore, nodular.	1–1 1/4	124 1/12
24. Dark gray calcareous shale with fossils.	9/6	122 5/6
23. *Mercer limestone.* Heavy dark blue limestone varying from 14 inches thick in one layer to 17 inches thick in two layers only fifteen feet away. The lower surface is somewhat irregular, and the limestone is fossiliferous, containing crinoid segments and brachiopod shells. The limestone does not become shaly on weathering as does that at Bald Knob and Flint Ridge, but breaks out in large rectangular blocks which retain their shape and are conspicuous in the bed of the stream for some distance below the horizon of the limestone.	1 1/6–1 5/12	113
22. Black bituminous shale.	1/2–2/3	111 7/12
21. Rather impure, blocky coal.	1/3–1 5/12	110 11/12
20. Thin black bituminous shale.	1 1/6	110 1/2

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
19. Fire clay.	$1\frac{1}{3}$	$109\frac{1}{3}$
18. Sandy shale and thin sandstone, showing some cross bedding at the base, light gray, buff or bluish.	$5\frac{1}{2}$	108
17. Argillaceous shale with some sand, light gray in color.	1	$102\frac{1}{2}$
16. Heavy sandy shale and thin sandstone, light gray, buff or bluish.	16	$101\frac{1}{2}$
15. Thin bedded dark blue or black shale.	$7\frac{5}{6}$	$85\frac{1}{2}$
14. Heavy bedded sandstone in the bed of the stream, buff in color on fresh surface, but weathers brown.	$4\frac{1}{3}$	$77\frac{2}{3}$
13. Heavy sandstone similar to that above.	$3\frac{2}{3}$	$73\frac{1}{3}$
12. Covered, partly sandy shale	15	$69\frac{2}{3}$
11. Thin, dark colored sandy shale weathering into small irregular pieces.	5	$54\frac{2}{3}$
10. Thin light gray or blue shale weathering into small rectangular pieces.	$7\frac{1}{2}$	$49\frac{2}{3}$
9. Black bituminous shale, coaly in some places, especially toward the top, and with blocky sandstone layers two or three inches thick. (Wellston coal horizon?)	4	$42\frac{1}{6}$
8. Light gray argillaceous shale, weathering to light gray or yellowish clay.	$2\frac{3}{4}$	$38\frac{1}{6}$
7. Soft argillaceous shale, dark blue or almost black.	3	$35\frac{5}{12}$
6. Covered interval. Traces of coal in the bed of the stream. (Sharon coal?)	$3\frac{2}{3}$	$32\frac{5}{12}$
5. *Sharon conglomerate.* Thick bedded, buff, coarse-grained quartz sandstone.	$4\frac{1}{6}$	$28\frac{3}{4}$
4. Dark blue sandy shale weathering brown, with partings and lenses of light buff or brownish sandstone.	$10\frac{5}{6}$	$24\frac{7}{12}$
3. *Maxville limestone.* Thick bedded gray or bluish limestone with some fossils. The heaviest bed, which is at the base, is about two feet in thickness.	$8\frac{1}{3}$	$13\frac{3}{4}$
2. Thin bedded blue limestone with shaly partings, quite fossiliferous.	$2\frac{5}{12}$	$5\frac{5}{12}$
1. Covered to the level of Jonathan creek.	3	3

Fossils collected from the Mercer limestone in Hough's Hollow:

Orthothetes crassus (Meek and Hayden)
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spirifer camaratus Morton
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Fossils collected from the gray calcareous shale which lies just above the Mercer limestone:

Lophophyllum profundum (Milne-Edwards and Haime)
Glossina waverlyensis Herrick
Orbiculoidea convexa (Shumard)
Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus semireticulatus (Martin)
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Dielasma cf. *turgidum* (Hall)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Edmondia ovata Meek and Worthen
Edmondia nebrascensis Geinitz
Leda bellistriata Stevens
Yoldia stevensoni Meek
Parallelodon carbonarius Cox
Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Aviculopinna americana Meek
Myalina swallovi McChesney
Aviculopecten coxanus Meek and Worthen
Acanthopecten carboniferus (Stevens)
Pecten (*Entolium*) *aviculatus* (Swallow)
Allorisma sp.
Pleurophorus oblongus Meek
Cypricardinia carbonaria Meek
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Dentalium sublaeve Hall

Bellerophon percarinatus Conrad
Euphemus carbonarius (Cox)
Euphemus nodocarinatus Hall
Bucanopsis montfortiana Norwood and Pratten
Pleurotomaria sp.

Orthoceras sp.

Crinoid segments and plates.

Stonehouse Hollow. Another section was taken in Stonehouse Hollow, on the opposite side of Jonathan creek and a mile northwest of Hough's Hollow, where the highway crosses the creek.

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
26. *Homewood sandstone.* Thin bedded gray, micaceous sandstone and shale.	10±	147⅚
25. Massive, coarse-grained buff or gray quartz sandstone. On the east side of the ravine a 12-foot ledge of this sandstone is shown with traces of coal and fire clay at the base (Tionesta coal?). About six feet from the base of this ledge is a fossil trunk of a tree 14 feet long. Base of *Homewood sandstone.*	12	137⅚
24. Thin light colored micaceous sandy shales, rather coarse.	4	125⅚
23. Iron ore horizon. One large nodule fallen from the bank measured two feet long, one foot wide, and one foot thick.	½±	121⅚
22. Thin gray calcareous shale with fossils.	12	121⅓
21. *Mercer limestone,* with iron ore at the top.	2	109⅓
20. Bituminous black shale with a four-inch layer of coal about the middle.	1	107⅓
19. Light gray fire clay.	3	106⅓
18. Thin gray sandy shale.	6	103⅓
17. Covered interval.	19⅚	97⅓
16. Heavy, compact fine grained sandstone, very light gray on fresh fracture, weathers buff or dark brown; shown on side of ravine. (Upper Massillon sandstone?)	2⅔	77½
15. Covered interval.	3½	74⅚

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
14. Thin bedded shale, black at the base but changing to light buff or gray at the top and becoming more sandy.	$28\frac{1}{3}$	$71\frac{1}{3}$
13. Thin black shale with numerous horizons of ore nodules, the most distinct being a two-inch layer six inches from the base, and a one-half to one inch layer ten inches from the base.	9	43
12. Black bituminous shale.	$\frac{5}{12}$	34
11. Impure coal. (Wellston coal?).	$\frac{1}{12}$	$33\frac{7}{12}$
10. Black bituminous shale.	$\frac{1}{6}$	$33\frac{1}{2}$
9. Light gray argillaceous shale, brownish when weathered; with some lenses of coal toward the top.	$4\frac{1}{2}$	$33\frac{1}{3}$
8. Heavy, cross-bedded, gray or buff sandstone, weathering brown. (Lower Massillon?).	$4\frac{2}{3}$	$28\frac{5}{6}$
7. Thin shale, black at the base, light gray at the top.	$11\frac{5}{6}$	$24\frac{1}{6}$
6. Black shale with nodules of iron ore.	$\frac{1}{3}$	$12\frac{1}{3}$
5. Thin black shale.	2	$11\frac{5}{6}$
4. Black shale with nodules of iron ore.	$\frac{1}{2}$	$9\frac{5}{6}$
3. Impure blocky coal with shaly partings in the lower part. (Sharon coal?)	$1\frac{1}{3}$	$9\frac{1}{3}$
2. Black bituminous shale.	1	8
1. Covered interval, to Maxville limestone in the bed of the stream near the railroad bridge.	7	7

Wortman's Ravine. On the south side of Jonathan creek directly opposite Stonehouse Hollow is another ravine where the Mercer limestone is exposed. In this ravine the interval between the Homewood sandstone and the Mercer limestone is much reduced, not exceeding 8 feet, and in one place being only one foot.

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
11. *Homewood sandstone.* Coarse grained gray or buff sandstone, fairly thin bedded.	15	$89\frac{7}{12}$
10. Massive gray or buff sandstone composed mostly of quartz grains. The lower part is very irregular and shows somewhat cross-bedded structure where it cuts out the shale below.	10–17	$74\frac{7}{12}$
9. Dark gray calcareous shale with fossils. The thickness of the shale varies on account of its being cut out by a "horseback" of the overlying sandstone.	1–8	$64\frac{7}{12}$

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
8. *Mercer limestone.* Heavy dark blue very hard limestone with some fossils which are obtained with difficulty, *Productus longispinus, Productus semireticulatus, Reticularia perplexa,* and crinoid segments.	1	$56\frac{7}{12}$
7. Black, somewhat shaly, rather soft limestone, very fossiliferous, but the fossils crushed and poorly preserved. *Seminula argentea, Productus longispinus, Productus nebraskensis, Chonetes mesolobus, Orthothetes crassus,* and *Astartella varica* were identified.	$\frac{2}{3}$	$55\frac{7}{12}$
6. Impure coal.	$\frac{1}{2}$	$54\frac{11}{12}$
5. Light gray sandy fire clay containing Stigmaria.	$\frac{5}{6}$	$54\frac{5}{12}$
4. Impure coal, hard and blocky.	$\frac{1}{4}$	$53\frac{7}{12}$
3. Fire clay similar to that above the coal.	1	$53\frac{1}{3}$
2. Gray sandy shale or thin sandstone with Stigmaria toward the top.	$16\frac{2}{3}$	$52\frac{1}{2}$
1. Thin black dark gray or blue arenaceous shale with black impressions resembling Stigmaria. Covered to the level of Jonathan creek, and not measured.	$35\frac{2}{3}$	$35\frac{2}{3}$

The Roberts' Ravine. In a ravine on the land of Harrison Roberts about half way between Wortman's Ravine and the village of Fultonham the Mercer limestone and the Homewood sandstone are exposed. The interval between them was not measured, but it is not more than eight or ten feet and consists entirely of the dark gray calcareous shale that is seen above the Mercer limestone in the other ravines studied.

From the Mercer limestone in this ravine the following species were collected:

Productus semireticulatus (Martin)
Productus longispinus Sowerby
Spirifer camaratus Morton
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Crinoid segments

The following fossils were obtained in the calcareous shale:

Lophophyllum profundum (Milne-Edwards and Haime)

Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Seminula argentea (Shepard)

Leda bellistriata Stevens
Yoldia stevensoni Meek
Parallelodon tenuistriatus Meek and Worthen
Schizodus curtus Meek and Worthen
Aviculopecten coxanus Meek and Worthen
Acanthopecten carboniferus (Stevens)
Pecten (Entolium) aviculatus (Swallow)
Allorisma sp.
Pleurophorus oblongus Meek
Cypricardinia carbonaria Meek
Astartella newberryi Meek
Astartella varica McChesney

Bellerophon percarinatus Conrad
Euphemus carbonarius (Cox)
Euphemus nodocarinatus Hall
Bucanopsis montfortiana Norwood and Pratten

Crinoid segments and plates.

The Allen Coal Entry. At the west end of Fultonham an entry has been made to Coal No. 5 on the land of Mr. Allen just north of the Zanesville and Maysville pike. Farther down the hill and across the road from the coal entry the Mercer limestone is exposed on a small branch of Bush creek. The limestone is here 2 feet and 8 inches thick with a layer of iron ore nodules on top 6 inches thick. Below the limestone coal and fire clay may be seen similar to that in Hough's Hollow. The iron ore on the top

of the limestone gives it a very irregular surface when weathered. The interval from the limestone to Coal No. 5 is 85 feet and is covered with the exception of two or three feet immediately above the limestone and ore, where the dark gray fossiliferous shale is exposed. This coal mine is not worked at present, but one-quarter to one-third of a mile farther west on the land of Mr. Hartness the same seam is worked in two mines. The thickness of the coal at these mines is given by the workmen as 4 feet and 8 inches, and the coal is of excellent quality. The workmen at these mines state that there is another vein of coal not far below No. 5, but not of workable thickness. The roof of the coal consists of soft sandy shale which in some parts of the mines has caved badly, causing depressions of considerable size on the hill above the entries. In one of these about 15 feet of the shale is shown in place above the coal.

Just back of the old toll house on the Zanesville and Maysville pike and not far from the exposure of the Mercer limestone where measured, a second limestone 8 to 10 inches thick was formerly exposed about 20 feet below the Mercer, but this lower limestone is now covered.

The following species of fossils were collected from the Mercer limestone below the Allen coal entry and on the adjoining land of Mr. Wm. Axline, where the limestone is shown in several places:

Rhombopora lepidodendroides Meek

Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus semireticulatus (Martin)
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Dentalium sublaeve Hall

Bellerophon crassus Meek and Worthen
Pleurotomaria sp.
Loxonema cerithiforme Meek and Worthen
Soleniscus fusiformis Hall
Soleniscus klipparti Meek

Phillipsia trinucleata Herrick
Crinoid segments and plates.

East Fultonham. In the hill behind the plant of the Fultonham Brick Company the Mercer limestone and underlying rocks are exposed in a cliff about sixty-five feet high. This exposure is the farthest east of any studied in this region, and is located near the Fultonham station on Jonathan creek.

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
11. Surface clay.		
10. *Mercer limestone.* Massive dark blue limestone which weathers lighter in color but does not become shaly to any extent; contains crinoid segments and brachiopod shells.	1½ ±	64¼
9. Coal.	¼	62¾
8. Fire clay with iron concretions.	8	62½
7. White micaceous sandstone containing a little fire clay.	4½	54½
6. Hard gray sandstone, rather thin bedded.	2½	50
5. Heavy micaceous sandstone, rather fine grained, buff or gray, which contains some iron concretions especially in the lower part, and is often iron stained. The workmen at the brick yard say this sandstone weathers to "bastard fire clay."	3½	47½
4. Shale and fire clay, upper part light colored, lower part darker, with numerous ore nodules.	12	44
3. Sandy light colored fire clay, sometimes replaced by hard bluish limestone, the upper 8 or 10 inches with abundant nodules of iron ore.	2	32
2. Blue shale.	18	30
1. Fire clay. Covered to the Maxville limestone in the banks of Jonathan creek; not measured.	12	12

The following fossils were collected from the Mercer limestone at the top of this section:

Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus semireticulatus (Martin)
*Productus cora d'*Orbigny
Productus longispinus Sowerby
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Zeocrinus sp.
Crinoid segments.

The Mercer limestone in the Fultonham region consists usually of a single hard compact layer of a dark blue color. In one or two places it is divided into two layers, but these are in contact without shale or other material separating them. A layer of iron ore is often found lying immediately upon the top of the limestone, which upon weathering gives it a very irregular upper surface. The limestone does not weather shaly as it does in the Bald Hill and Flint Ridge regions, but breaks out in large rectangular blocks which retain their shape when weathered. In the older valleys and along the hillsides where the other members of the Pottsville and Allegheny formations have been covered with soil and vegetation the limestone blocks are often quite conspicuous and mark the horizon of the Mercer. This is particularly true in the open fields to the south and west of the village, and along Bush creek toward Somerset. It is a noticeable fact that, whereas in the gullies formed by the younger streams the Homewood sandstone is the conspicuous member exposed, often forming cliffs along the valley walls while the lower members of the Pottsville formation and those of the Allegheny formation above are frequently covered with soil, in the older valleys the Mercer limestone is the member left exposed after all the others are covered.

The fauna of the limestone in this region differs somewhat from that of the exposures at Bald Knob and Flint Ridge, the principal difference being in the almost complete absence of the small pelecypods so abundant in those localities. The gray calcareous

shale overlying the limestone, however, carries the same pelecypod fauna as the shaly limestone farther northwest. The one pelecypod obtained from the limestone in this vicinity was collected at the section studied farthest northwest, where the lower part of the limestone is somewhat shaly and softer than in any of the other exposures. The most conspicuous fossils in the limestone about Fultonham are the large crinoid segments with pentamerous centers. The organic part of the segments has been replaced by calcite, which presents quite a contrast to the dark blue limestone surrounding the segments and filling the centers. Crinoid stems several inches long are not uncommon, and occasionally one is found as much as two feet in length.

SOMERSET

Southwest from Fultonham the Mercer limestone shows a tendency to become thicker, and in the cut along the Baltimore and Ohio Railroad south of Somerset it is exposed with a thickness of 4 feet and 8 inches. The limestone here is in one massive layer with the upper part flinty in places, and is dark blue or almost black in color. The lower part of the limestone is very fossiliferous, showing a great variety of species. In general appearance the limestone is not unlike that at Fultonham; but it breaks much more easily and weathers somewhat shaly, in these respects, as well as in fossil contents, more closely resembling the limestone at Bald Knob and Flint Ridge.

Above the limestone a few fragments of very thin brittle black shale were found, which contained very small gasteropod shells. Below the limestone is a layer of black bituminous shale which is more coaly toward the top; and below this is a fire clay.

The following collection of fossils was made from the limestone:

Fenestella shumardi Prout
Septopora biserialis Swallow
Prismopora sereata Meek
Orbiculoidea convexa (Shumard)
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten

Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Rhipidomella pecosi (Marcou)
Spiriferina kentuckiensis (Shumard)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Solenomya radiata Meek and Worthen
Solenomya anodontoides Meek
Edmondia nebrascensis Geinitz
Parallelodon carbonarius Cox
Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Schizodus wheeleri Swallow
Aviculopecten coxanus Meek and Worthen
Aviculopecten occidentalis (Shumard)
Aviculopecten herzeri Meek
Acanthopecten carboniferus (Stevens)
Pecten (Entolium) aviculatus (Swallow)
Entolium attenuatum Herrick
Lima retifera Shumard
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek

Cypricardinia carbonaria Meek
Astartella newberryi Meek
Astartella varica McChesney

Dentalium sublaeve Hall
Euomphalus sp.
Conularia sp.
Crinoid segments.

ELIZABETH

At Elizabeth, a station on the Zanesville and Western Railroad between Fultonham and Zanesville, the Homewood sandstone and underlying shale are exposed in a cliff along Jonathan creek, by the dam just above the highway bridge. The cliff was not meas-

ured, but there appears to be about 20 feet of the Homewood sandstone, which here shows an irregular lower surface similar to that in Wortman's Ravine near Fultonham. Just above the bridge a very thin seam of coal is shown at the base of the sandstone. Below the sandstone are 30 feet or more of black to gray shales; and blocks of what is apparently Mercer limestone are visible in the bed of the stream at the bridge. From Elizabeth to Zanesville along the line of the Zanesville and Western Railroad, frequent exposures of the Homewood are seen, many of them showing in the lower part the cross-bedding and other irregularities that indicate disconformity.

ZANESVILLE

Putnam Hill. At the base of Putnam Hill in Zanesville the Mercer limestone appears in the bed of the Muskingum river, the Upper Mercer limestone a short distance above water level, and the Putnam Hill limestone farther up the hill at the side of the road on the dugway. The section from river level to the upper limestone is as follows:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
16. Gray shale above Putnam Hill limestone.	25	116½
15. *Putnam Hill limestone.* Type locality. Heavy bluish gray limestone.	3½	91½
14. Black fossiliferous shale.	⅙–2⅙	88
13. Coal (Clarion?).	¾	85⅚
12. Fire clay, Putnam Hill. This is gray or yellowish and not of the best grade.	3¾	85½
11. Black or sometimes bluish shale.	4½	81½
10. Impure coal and shale (Brookville?).	1	77
9. Gray shale or clay to the level of the road. All the rocks exposed above the level of the road belong in the Allegheny formation.	4¾	76
8. Covered interval.	42	71¼
7. Mainly arenaceous shale, grayish in color.	3⅙	29¼
6. Bluish argillaceous shale.	4	25¾

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
5. *Homewood sandstone.* Heavy, buff, coarse-grained sandstone, rather soft and micaceous. A few rods farther south this sandstone is much thicker and shows disconformity associated with cross-bedding, folding and faulting in the lower part.	3⅔	21¾
4. Gray arenaceous shale. About 1½ or 2 feet below the sandstone is a concretionary layer in the shale.	4⅓	18 1/12
3. Bluish-black shales which are very thin and break into very small pieces.	8 5/12	13¾
2. *Upper Mercer limestone*, with limonite ore. There are four layers of the limestone shown, the upper one 6 to 8 inches thick and containing iron ore, the next a 5-inch layer without a conspicuous amount of ore, a 5-inch layer with iron ore, and the lowest a 10-inch layer without the ore. The limestone is dark gray, weathering almost black except where the iron ore gives it a dark red or brown color. Fossils appear to be very scarce.	2⅓	5⅓
1. Covered to water level. All of the lower part of the section, from the road on the dugway to river level belongs in the Pottsville formation.	3	3

The Weller Pottery. In the cliff behind the Weller Pottery, which is located on the north side of the Zanesville and Western Railroad not far from the Putnam station, an excellent exposure of the Homewood sandstone is shown. The section is as follows:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
4. Alternating shales and sandstones, some of the shales being very fossiliferous, with remains of trees, etc.	22 1/6	53⅓
3. Brookville coal.	1⅚	31⅙
2. Dark, almost black, shale or fire clay.	1⅚	29⅓
1. *Homewood sandstone.* Top of the Pottsville formation. The sandstone is very thick and massive, some of the layers being 10 feet thick. It is coarse and micaceous, and is a dark steel-gray in color, sometimes iron-stained. Below the floor of the quarry 20 feet more of Homewood sandstone are said to be buried.	27½	27½

ROSEVILLE

The Mercer limestone is apparently below drainage level at Roseville, and the Putnam Hill limestone is exposed 47 feet above the level of the south branch of Moxahala creek at the brick yard just north of the town. The following section was measured in the lower part of this hill:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
8. Shale and sandstone.	10±	81⅚
7. Lenticular or nodular layer of sandstone, gray with brown streaks when weathered; shows cross-bedded structure.	1-2	71⅝
6. Blue clay shale with some sand (makes "vitreous" brick).	20±	69⅝
5. *Putnam Hill limestone.* A single layer of gray or bluish gray crystalline limestone which weathers brown or buff. The upper 4 inches is not very fossiliferous, but the lower part is quite fossiliferous, the fossils weathering out in relief. The limestone contains many crinoid segments, and is very hard and massive.	2½	49⅝
4. Coal.	⅓	47⅓
3. Fire clay.	3	47
2. Massive sandstone, buff streaked with brown when weathered.	5	44
1. Covered to water level.	39	39

The following fossils were found in the Putnam Hill limestone at this locality:

Productus semireticulatus (Martin)
Productus cora d'Orbigny
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney) (small, numerous)

Bellerophon carbonarius (Cox)?

Small crinoid segments.

On the land of Mr. Ryland in the northern part of Roseville the Putnam Hill limestone was formerly quarried to some extent

and used in the manufacture of lime which is said to have been dark colored, but strong and of good quality.

A mile and a half west of Roseville, on Eel Run an oil well has recently been drilled on the land of David Allen, of which the following record was obtained:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
10 inch pipe	40	40
Clay and slate	70	110
Lime and iron	35	145
Slate and shale	250	395
Salt sand and slate	155	550
8-inch casing	...	550
Slate and shale	350	900
Berea sand	10	910
Red rock	10	920
6½-inch casing	....	920
Brown shale	450	1370
Cinnamon	150	1520
Slate and shale	450	1970
Big cinnamon	250	2220
Slate	90	2310
Brown shells and iron	15	2325
Top of lime	....	2325
Bottom of lime	....	3280
Top of sand	....	3432
Bottom of sand	....	3476
Total depth	....	3479
Water at 3050		

The 955 feet of limestone in this record evidently includes the Devonian, Monroe and Niagara limestones. The figures for this well, as compared with those for the well at Flint Ridge, are as follows:

	ROSEVILLE	FLINT RIDGE
From derrick floor to Berea Grit	900	850
Berea Grit	10	15
From Berea Grit to limestones	1415	955
Devonian, Monroe & Niagara limestones	955	900
From limestones to Clinton sand	152	168
Clinton sand	44	44

It will be observed that the greatest variation is in the interval between the Berea grit and the top of the limestone. This place in the geological scale is occupied by the Bedford and Ohio shales. The difference of the thickness of these shales at Flint Ridge and Roseville is 460 feet, and as the two wells are approximately 17 miles apart, this would mean an average increase of 27 feet per mile in the thickness of the shales, from northwest to southeast. This agrees closely with Dr. Bownocker's statement in regard to the thickening of these formations toward the east, in his bulletin on oil and gas (*Geological Survey of Ohio,* Fourth Series, Bulletin No. 1, 1903, p. 119).

SUMMARY

The exposures of the Mercer limestone at Bald Knob and Flint Ridge show the same lithological character and carry the same fauna. The thickness at Bald Knob could not be measured, but at Flint Ridge the greatest thickness is about 14 feet, and the limestone is underlain by cannel coal of workable thickness. The greater part of the limestone is shaly and fossiliferous, but there is a layer of impure, very fossiliferous limestone at the top and a somewhat thicker part of heavy, only moderately fossiliferous limestone at the bottom. The fossils are mostly brachiopods and small pelecypods, the number of species of pelecypods being two or three times as great as the number of species of brachiopods.

In the Fultonham region the greatest thickness of the Mercer limestone is a little less than 3 feet, and it consists of a single massive layer that does not become shaly on weathering. The underlying coal is not more than 6 inches thick. Above the limestone is a gray calcareous shale in which are found many of the pelecypods and other fossils of the Flint Ridge region. The limestone itself carries principally a brachiopod and gasteropod fauna, only one pelecypod being found. The interval from the base of the Sharon conglomerate to the Mercer limestone is much less than at Bald Knob, and the whole section seems to be shortened.

At Somerset the limestone is a little less than 5 feet thick, and its general appearance when in place is similar to that of the Mer-

cer limestone at Fultonham, though it is more nearly black and contains some flint. When weathered it becomes shaly, and more closely resembles the limestone at Flint Ridge and Bald Knob; and it contains the same fossils as the limestone at those localities.

The entire list of fossils collected from the Mercer limestone at all of the exposures studied is as follows:

Lophophyllum profundum (Milne-Edwards and Haime)

Fenestella shumardi Prout
Septopora rectistyla Whitfield
Septopora biserialis Swallow
Prismopora sereata Meek
Rhombopora lepidodendroides Meek

Glossina waverlyensis Herrick
Orbiculoidea convexa (Shumard)
Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus semireticulatus (Martin)
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Rhipidomella pecosi (Marcou)
Dielasma cf. *turgidum* (Hall)
Spiriferina kentuckiensis (Shumard)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Solenomya radiata Meek and Worthen
Solenomya anodontoides Meek
Prothyris elegans Meek
Edmondia cf. *aspinwallensis* Meek
Edmondia ovata Meek and Worthen
Edmondia reflexa Meek
Edmondia nebrascensis Geinitz

Nucula beyrichi von Schauroth
Nucula parva McChesney
Leda bellistriata Stevens
Yoldia stevensoni Meek
Parallelodon carbonarius Cox
Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Parallelodon sangamonensis
Aviculopinna americana Meek
Avicula ohioense Herrick
Myalina swallovi McChesney
Schizodus cuneatus Meek
Schizodus curtus Meek and Worthen
Schizodus wheeleri Swallow
Aviculopecten coxanus Meek and Worthen
Aviculopecten occidentalis (Shumard)
Aviculopecten herzeri Meek
Aviculopecten cf. *fasciculatus* Keyes
Acanthopecten carboniferus (Stevens)
Euchondria neglecta Geinitz
Pecten (Entolium) aviculatus (Swallow)
Entolium attenuatum Herrick
Lima retifera Shumard
Placunopsis carbonaria Meek and Worthen
Allorisma terminale Hall
Allorisma sp.
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek
Pleurophorus subcostatus Meek and Worthen
Cypricardinia carbonaria Meek
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Dentalium sublaeve Hall

Bellerophon crassus Meek and Worthen
Bellerophon percarinatus Conrad
Euphemus carbonarius (Cox)
Euphemus nodocarinatus Hall

Bucanopsis marcouana Geinitz
Bucanopsis montfortiana Norwood and Pratten
Pleurotomaria broadheadi White.
Pleurotomaria sp.
Euomphalus catilloides Conrad
Euomphalus sp.
Loxonema cerithiforme Meek and Worthen
Bulimorpha inornata Meek and Worthen
Soleniscus fusiformis Hall
Soleniscus klipparti Meek

Conularia sp.

Nautilus sp.
Orthoceras sp.

Phillipsia major Shumard
Phillipsia trinucleata Herrick

Zeocrinus sp.
Crinoid segments and plates.

In the naming and arrangement of these fossils Dr. A. W. Grabau's Index Fossils and Stuart Weller's Bibliographic Index of North American Carboniferous Invertebrates have been followed.

PLATE VIII

1. *Glossina waverlyensis* Herrick, Limestone Hollow, Flint Ridge.
2. *Orbiculoidea convexa* (Shumard), Bald Knob.
3. *Orbiculoidea missouriensis* Shumard, Cannel Coal Mine, Flint Ridge.
4. *Orthothetes crassus* (Meek and Hayden), Bald Knob.
5. *Chonetes mesolobus* Norwood and Pratten, ventral valve, x 2, Cannel Coal Mine, Flint Ridge.
6. *Chonetes mesolobus* Norwood and Pratten, dorsal valve, x 2, Cannel Coal Mine, Flint Ridge.
7. *Productus longispinus* Sowerby, Limestone Hollow, Flint Ridge.
8. *Spiriferina kentuckiensis* (Shumard), Bald Knob.
9. *Spirifer camaratus* Morton, Somerset.
10. *Spirifer rockymontanus* Marcou, Somerset.
11. *Reticularia perplexa* (McChesney) Bald Knob.
12. *Seminula argentea* (Shepard), ventral valve, Cannel Coal Mine, Flint Ridge.
13. *Seminula argentea* (Shepard), dorsal view, Limestone Hollow, Flint Ridge.
14. *Soleniscus klipparti* Meek, Limestone Hollow, Flint Ridge.

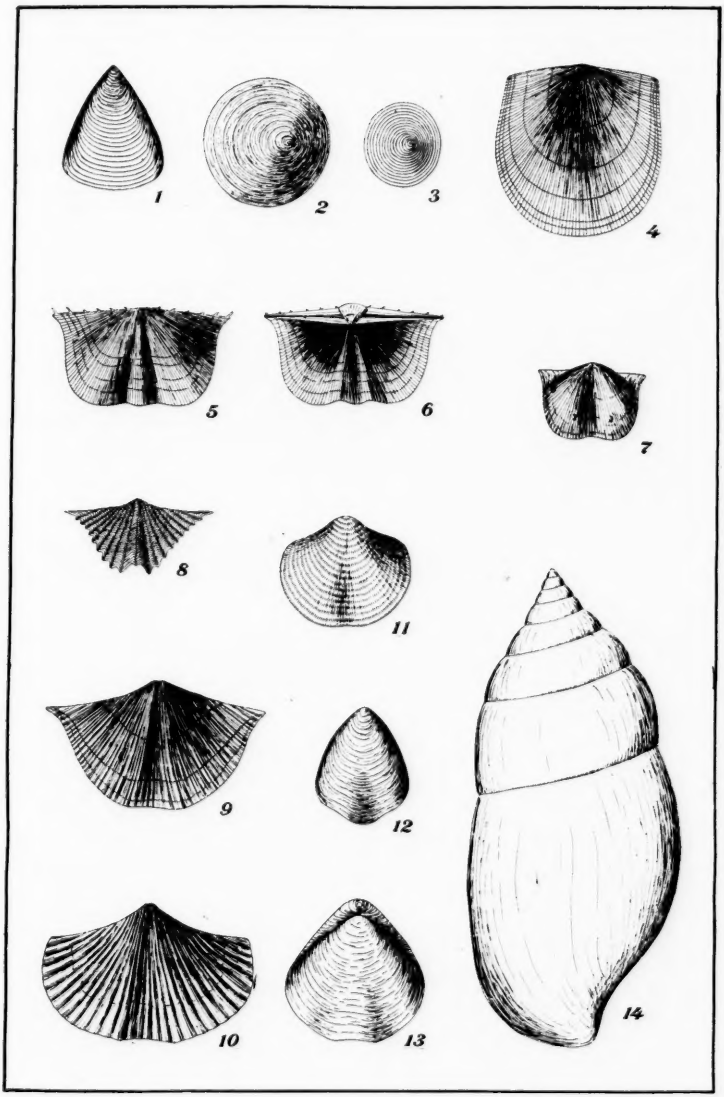

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PLATE IX

1. *Solenomya radiata* Meek and Worthen, Somerset.
2. *Solenomya anodontoides* Meek, Limestone Hollow, Flint Ridge.
3. *Edmondia reflexa* Meek, Cannel Coal Mine, Flint Ridge.
4. *Edmondia nebrascensis* Geinitz, Bald Knob.
5. *Leda bellistriata* Stevens, x 2, Limestone Hollow, Flint Ridge.
6. *Yoldia stevensonia* Meek, Limestone Hollow, Flint Ridge.
7. *Parallelodon carbonarius* Cox, Cannel Coal Mine, Flint Ridge.
8. *Parallelodon tenuistriatus* Meek and Worthen, Bald Knob.
9. *Parallelodon obsoletus* Meek, Cannel Coal Mine, Flint Ridge.
10. *Parallelodon sangamonensis*, Bald Knob.
11. *Avicula ohioensis* Herrick, Cannel Coal Mine, Flint Ridge.
12. *Myalina swallovi* McChesney, x 2, Bald Knob.
13. *Schizodus cuneatus* Meek, Limestone Hollow, Flint Ridge.
14. *Schizodus curtus* Meek and Worthen, Cannel Coal Mine, Flint Ridge.

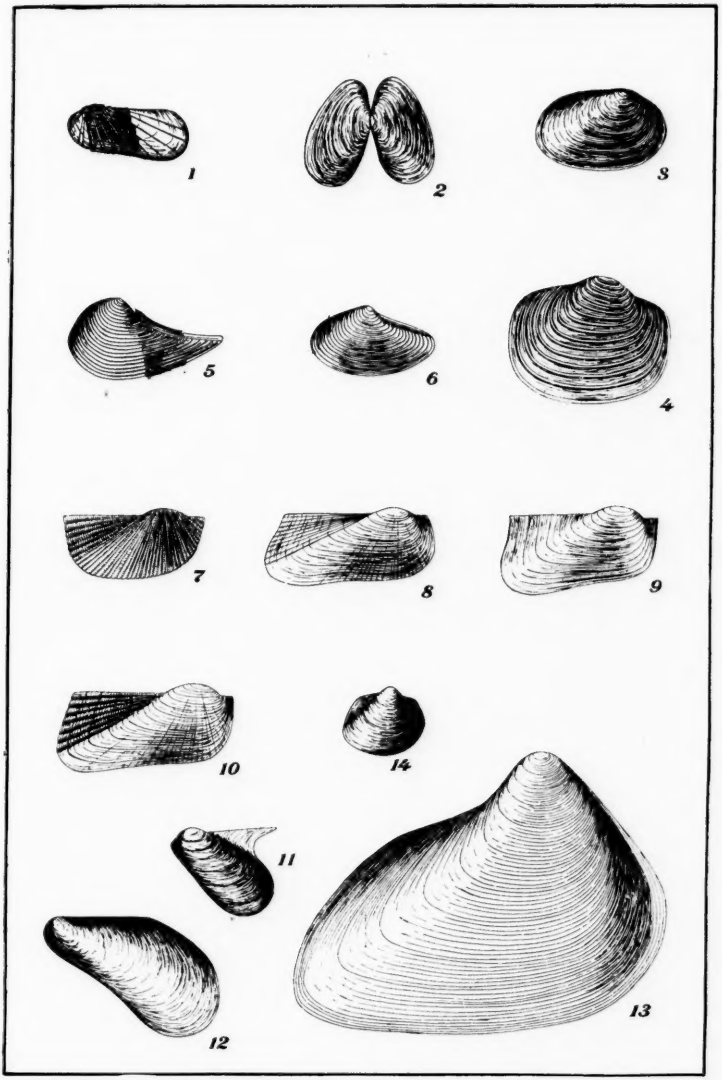
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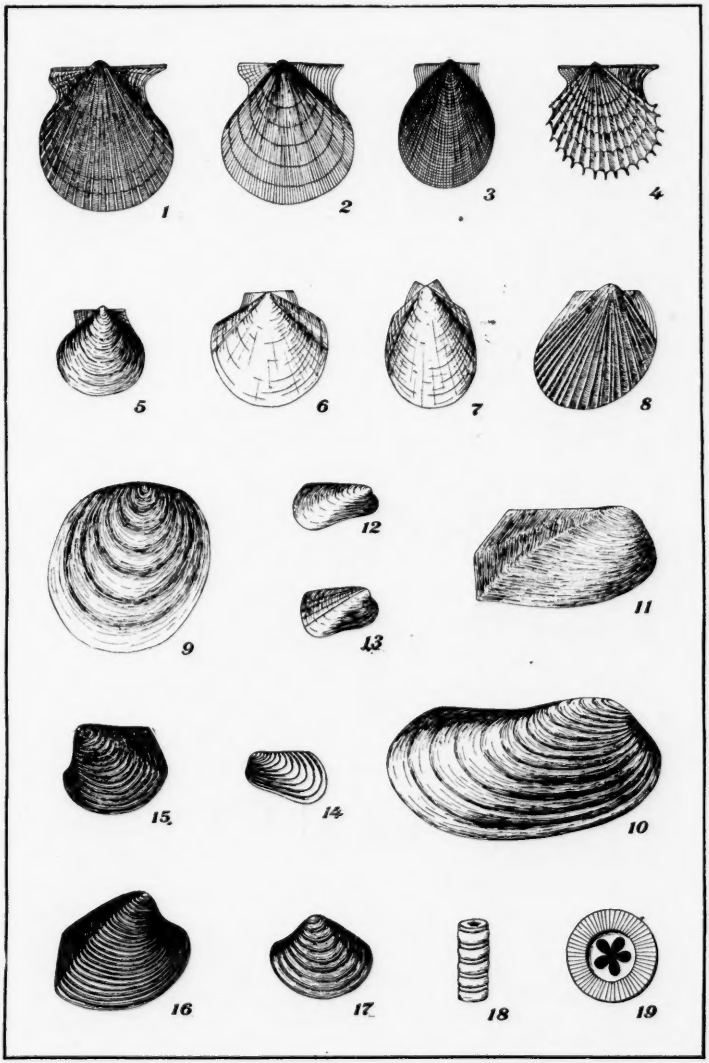
PLATE X

1. *Aviculopecten coxanus* Meek and Worthen, x 2, Cannel Coal Mine, Flint Ridge.
2. *Aviculopecten occidentalis* (Shumard), x 2, Bald Knob.
3. *Aviculopecten herzeri* Meek, x 2, Somerset.
4. *Acanthopecten carboniferus* (Stevens) Bald Knob.
5. *Euchondria neglecta* Geinitz, x 2, Bald Knob.
6. *Pecten (Entolium) aviculatus* (Swallow) Limestone Hollow, Flint Ridge.
7. *Entolium attenuatum* Herrick, Cannel Coal Mine, Flint Ridge.
8. *Lima retifera* Shumard, x 2, Limestone Hollow, Flint Ridge.
9. *Placunopsis carbonaria* Meek and Worthen, Cannel Coal Mine, Flint Ridge.
10. *Allorisma terminale* Hall, Cannel Coal Mine, Flint Ridge.
11. *Pleurophorus tropidophorus* Meek, Limestone Hollow, Flint Ridge.
12. *Pleurophorus oblongus* Meek, Bald Knob.
13. *Pleurophorus subcostatus* Meek and Worthen, Limestone Hollow, Flint Ridge.
14. *Cypricardinia carbonaria* Meek, Bald Knob.
15. *Astartella vera* Hall, Limestone Hollow, Flint Ridge.
16. *Astartella newberryi* Meek, Cannel Coal Mine, Flint Ridge.
17. *Astartella varica* McChesney, Limestone Hollow, Flint Ridge.
18. Crinoid segments, Somerset.
19. Crinoid segment, Fultonham.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A STUDY OF THE SUPPOSED HYBRID OF THE BLACK AND SHINGLE OAKS[1]

(Contribution from the Botanical Laboratory of Denison University, No. XI)

EARL HARRINGTON FOOTE

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HISTORICAL SKETCH OF QUERCUS LEANA

Quercus Leana Nutt., a supposed hybrid between the two species *Q. imbricaria* Michx. and *Q. velutina* Lam., received its name from Mr. T. G. Lea who discovered a single specimen near Cincinnati, Ohio, about seventy or eighty years ago. A part of Lea's description of the tree reads as follows:

> If a hybrid, it may have come from the *Q. imbricaria* or *Q. tinctoria* (*velutina*) or *Q. coccinea*. The fruit is too widely different from *Q. rubra*. The peduncles are about the same length as in my specimens of *Q.*

[1] Work done under the direction of Prof. Malcolm E. Stickney as part requirement for the degree of Master of Science, Denison University.

imbricaria. The petioles are much longer than in *Q. imbricaria*, the leaves larger and more obtuse at base. These modifications (if it is a hybrid) may be derived from the long petioles and larger leaves of the black and scarlet oaks. I have found but a single stock of this (about five years ago). It grows three miles north of Cincinnati.[2]

Thomas Nuttall,[3] in commenting on these lines differed with Mr. Lea, expressing the belief that the new oak was a distinct species allied to the black or red oak. He said,

I confess I see too little resemblance in our plant with *Quercus imbricaria* to agree with my friend, Mr. T. G. Lea, as to any hybrid connection with that remotely allied species. Betwixt the gray oak (*Q. ambigua* Mich.), and *Q. tinctoria* I perceive a nearer resemblance. The fruit appears to be wholly that of the gray oak. The gland in both is striated and with a small conic projection. In our plant, however, the base of the gland and that of the cup are yellow, indicating its alliance to *Q. tinctoria*. The leaf differs wholly from both in its simple undivided lobes, though the long petioles and rounded base is that of *tinctoria*. Scarce as this species yet appears to be, under the present circumstances, I am inclined to believe it is of a distinct race, with features as distinct as any species in the genus; for the gray oak, being, I believe, unknown in Ohio, is again out of the question. I suspect it is in all physical respects allied to *tinctoria* and would equally afford a yellow dyeing material.

The full grown leaves are from five to five and a half inches long by three to three and a half wide, smooth and shining above, with a small quantity of deciduous stellate pubescence beneath. The lobes are about a single pair on a side, the central lobe only sometimes again subdivided into three lesser lobes all of them ending in bristles. The base is rounded, and often hollowed out, or somewhat sinuated. The buds are small and brown. The fertile flower often by threes, on a short, thick common pedicel, the middle flower abortive. Male flowers not seen. Cups rather deep, as in *Quercus tinctoria* with the scales ovate, obtuse, and closely imbricated. The acorn roundish, somewhat ovate, broadly striate, with short roundish conic point or umbo about half-way, or nearly so immersed in cup.

Some years later Lester F. Ward[4] discovered two trees in the District of Columbia which he identified as *Leana*, comparing them with the specimens in the Herbarium of the Department of Agriculture. He says:

[2] Nuttall, *North American Sylva*, vol. i, p. 25, 1865.
[3] *Ibid.*, pp. 25–27.
[4] *Field and Forest*, vol. i, p. 41, 1865.

Two trees which I have recently discovered in a wood near the northwestern (northern) corner of the District of Columbia, have proved unusually interesting. That these should be called *Quercus Leana* and not *Q. heterophylla* I maintain for the following reasons: Their resemblance to *Q. heterophylla* as it exists in the Herbarium of the Department of Agriculture is not sufficiently close to warrant this name, the leaves being broader and less lobed. They do agree substantially with the specimens of *Q. Leana* in that herbarium. They do agree remarkably well with the tree which Mr. W. R. Smith, Supt. of the U. S. Botanical Gardens, has raised in his grounds from an acorn of *Q. imbricaria*. Finally on considering the locality in which these trees were found, it seems impossible to believe that *Q. Phellos* can have entered into the combination. In the entire wood where they are situated not an individual of that species exists. It is wholly wanting throughout the region of Rock Creek on which the grove is located. On the contrary the prevailing oak there is *Q. imbricaria* although both varieties of *Q. coccinea* are also frequent. It cannot therefore be justly claimed that this new discovery constitutes a revival of the famous Bartram oak, since this was decided on the highest authority to be either a form of *Q. Phellos* or a union of that species with *Q. coccinea* var. *tinctoria*. It is none the less however a botanical curiosity.

Sargent[5] next takes up the subject and says:

This tree has generally been considered a natural hybrid between *Q. imbricaria* and *Q. coccinea* or *Q. tinctoria*. It is now known in several widely scattered localities, from the neighborhood of Washington, D. C. to Missouri, and there seems no reason . . . . why, if *Q. heterophylla*, which many excellent observers have always considered a hybrid, is included as a species in the American Sylva, *Q. Leana* should not be included also. It should follow immediately after *Q. imbricaria* with which its relationship is obvious.

Following this I can find no mention of *Q. Leana* until 1909 when Mr. Saur[6] gives a description of the three trees, *imbricaria*, *velutina*, and *Leana*, and notes the following facts pointing toward the conclusion that *Leana* is a hybrid between *velutina* and *imbricaria:*

1. Hundreds of acorns have been planted but there is no record of one having germinated.
2. The leaves closely resemble those of the shingle oak.
3. The few specimens discovered are isolated from each other.
4. The cup and the fruit bear marked resemblance to those of the black oak.

[5] *Garden and Forest*, vol. ii, p. 471.
[6] *Plant World, vol. 12*, No. 9, Sept., 1909.

Sargent[7] in his *Sylva of North America* gives *Leana* a place with *imbricaria*; and in his *Trees of North America*, he says[8] that *Q. Leana* is believed to be a hybrid between *Q. imbricaria* and *Q. velutina*. Britton in his "*Flora of United States and Canada*,"[9] says that *Q. Leana* is a hybrid between *Q. imbricaria* and *Q. velutina*, while the new Gray manual makes no mention of it whatever.

Historically then we see that Nuttall is the only one to consider *Leana* a distinct species, and that the other men have considered it a natural hybrid between *imbricaria* and either *velutina* or *coccinea*. Mr. Ward favored *coccinea*, but the later men, Sargent and Britton, have returned to Lea's first suggestion and have considered *velutina* the other parent. Lea mentions *Q. rubra* but disproves the possibility of it having entered into the combination, their fruits differing widely. Mr. Nuttall mentions *Q. ambigua*, the gray oak, and his statement that the fruit "appears to be wholly that of the gray oak" can be neglected because the gray oak is no longer recognized as a species. Mr. Ward mentions *Q. Phellos* and gives the reason for not considering it that it was not found in the locality of his hybrids. It is not found in the vicinity of Cedar Point and need not be considered here.

Description of Cedar Point Representatives

On Cedar Point there are several trees that have been considered by the late Professor Kellerman, Professor Jennings and others to be representatives of Lea's oak. Cedar Point is an almost isolated piece of land and while oaks are very abundant there, they are confined to practically three species: *imbricaria*, *velutina*, and *rubra*. These with one or two representatives of *macrocarpa* and the half dozen or so representatives of Lea's oak mentioned above complete the list. Professor Moseley[10] mentions one oak of a hybrid nature which he suggests may be a cross between *imbricaria* and *Marilandica*. In 1910 a tree was

[7] Vol. viii, p. 176, 1895.
[8] P. 252, 1905.
[9] Vol. i, p. 520, 1896.
[10] *Sandusky Flora*, p. 73, 1899.

found by Mr. Simkins several miles southeast of the Laboratory, which may answer to this description.

In 1910 Professor Jennings called my attention to another oak which shows hybrid characters. The leaves resemble those of *velutina* and have long yellowish petioles which show plainly when one is approaching the tree, giving it a striking appearance. Some of the leaves are less lobed than others and all show a characteristic curve in the vertex of the lobe. Seedlings close by indicate that its fruit which is like that of *velutina* is fertile.

Since I have studied two of these trees identified as *Leana* more closely than the others it may be well to describe them in particular. One of them is on the top of a sand dune nearly midway between the lake and Beimiller's cove about a hundred and twenty yards north west of the State University Lake Laboratory. The tree is about twenty-five or thirty feet high, its trunk at the base about sixteen or eighteen inches in diameter. The tree is but little shaded, and its horizontal somewhat pendulous branches arise within six or seven feet from the ground. These almost touch the branches of an *imbricaria* just to the east. At present the tree is being covered with grape vines and a number of its branches are dying. This tree we may for convenience refer to as tree *A*. The other tree is perhaps thirty yards farther northwest and is nearer the cove. It is about forty feet tall, its trunk about twenty or twenty-two inches in diameter at the base. Its first horizontal somewhat pendulous branches arise about twelve or fifteen feet from the ground. The tree, situated in an *imbricaria* grove, is in a lower place than tree *A* and is in better condition. We may refer to this tree as tree *B*.

The general habit, rather smooth brownish bark, branching, and imbricated leaf arrangement of both trees resemble that of *imbricaria*. In tree *B* the angle between the branches and the trunk is more acute and the branches more ascending for a short distance. An examination of their leaves shows intermediate characters between the entire oblong-lanceolate or oblong-ovate leaves of *imbricaria* and the five to seven lobed obovate leaves of *velutina*. The most distinctive leaf is slightly obovate and three lobed, each lobe ending in a bristle. Some of the leaves are hardly to be distinguished from those of *imbricaria* while others are quite deeply five to seven lobed. Where the leaves are entire or only slightly lobed their margins are often somewhat crisped. In shaded places

very large leaves practically like the juvenile leaves of *velutina* are often found.

The leaves of tree *A* are smaller than those of tree *B* and the distinctive three lobed apex is often found, while in tree *B* the leaves are generally five or seven lobed and rarely show a three lobed apex. The leaves of tree *A* measure $8\frac{1}{2}$ to 13 cm. by $3\frac{3}{4}$ to 8 cm.; those of tree *B*, 11 to $17\frac{1}{2}$ cm. by 4 to $12\frac{1}{2}$ cm. The petiole is longer than that in *imbricaria* and the base more obtuse, characters suggesting *velutina*. The leaves are arranged on the stem in a fashion very similar to those of *imbricaria* giving almost the characteristic shingle appearance. On a twig of a single year's growth the leaves at its beginning are lobed but not as deeply as those in the middle and toward the end, but at the end of the stem, contrary to what one would expect, there are usually one or more leaves which are entire and practically like *imbricaria* leaves (plates XI and XII). The young leaves of *imbricaria* are covered on the lower side with a thick hoary tomentum, while there is a scurfy pubescence on the upper side. In the bud of *imbricaria* the leaves are involute, while in *velutina* and *Leana* they are convolute. Sargent[11] mentions this.

In both trees of *Leana* the acorn, with its turbinate cup which has closely appressed hoary scales fringed at the rim, is more nearly like that of *velutina* than *imbricaria* and is so unlike that of *rubra* that the red oak is out of the question. The male flowers of tree *A* have peduncles that are intermediate in length between those of *imbricaria* and *velutina*, while the peduncles of tree *B* are equal in length to those of *velutina*. *Imbricaria* peduncles are about 4 cm. in length, *velutina*, 8 to $8\frac{1}{2}$ cm., *Leana*, tree *A*, 6 to $6\frac{1}{2}$ cm., and tree *B*, 8 to 9 cm.

Owing to the inaccessibility of Cedar Point continuous observation of the trees cannot be made from Granville, but on May 14, 1910, I found that the pistillate flowers of all three kinds had matured, and that good staminate flowers of *velutina* were very scarce, the anthers having shed their pollen in nearly all cases. Good specimens of staminate flowers of *imbricaria* and *Leana* were abundant. Therefore I conclude that the stigmas of the pistillate flowers on a tree ripen before the anthers of its staminate flowers, thereby securing cross fertilization. The slight dif-

[11] *Sylva of North America*, vol. viii, p. 176, 1895.

ference in the time of maturity of the two kinds of flowers of *velutina* and *imbricaria* may be very significant. The first ripened pistils of *imbricaria* are ready for pollination before *imbricaria* pollen is available, but when there is an abundance of *velutina* pollen. Thus a favorable condition for hybridization is brought about, and at the same time the direction in which such hybridization will take place is strongly indicated. In other words *imbricaria* must be the maternal and *velutina* the paternal parent. Such an assumption is further borne out by the position of the trees in question at Cedar Point, all being near *imbricaria* trees, with *velutina* trees more or less distant. The assumption also is in harmony with Mr. Ward's account of a *Leana* raised by Mr. W. R. Smith from an acorn of *imbricaria*.

Gross Anatomy of the Stem

The oaks have characteristically a sharply five angled pith and conspicuous broad medullary rays. The pentagonal pith of the three oaks in question is decidedly asymmetrical, being considerably longer than broad. In *velutina* it is in general much larger than in the other two, and averages nearly twice as long as broad. The smaller pith of *imbricaria* has much the same shape, being both shorter and narrower. *Leana* has a greatly elongated and much compressed pith, thus presenting in one dimension the condition of *velutina*, and in the other that of *imbricaria* (plate XIV, figs. 1–3).

In small branches of *imbricaria*, 1 cm. in diameter, the broad rays are conspicuously arranged in pairs producing with the enclosed wood masses the appearance of five distinct radiating bands. Certain other oaks also possess this feature, noticeably the English oak (*Q. robur*), where the radiating bands are more narrow but equally conspicuous. *Velutina*, on the other hand, shows numerous large medullary rays in addition to the five pairs at the angles of the pith, and the bands, so striking in *imbricaria*, are hardly conspicuous here. *Rubra* and *coccinea* present much the same condition as *velutina* in this respect, although in *rubra* the rays are somewhat less distinct, and the bands even less evident, while in *coccinea* the more numerous rays are rather regularly distributed and the bands disappear altogether. *Leana*

shows a condition strikingly like *velutina* save that the bands are more distinct (Plate XIII, figs. 1–8).

The composition of the annual ring presents certain significant features. The spring wood which in all three is not sharply defined, in *imbricaria* appears in the form of a fairly regular band of large tracheæ of nearly uniform size extending completely across the space between two broad medullary rays, with very little of wood masses included. In *velutina* the tracheæ are not so uniform in size and show a tendency to be grouped together in irregular shaped areas interspersed with wood masses. In *Leana* the vessels are perhaps more nearly uniform in size as in *imbricaria* but they show a tendency toward bunching as in *velutina*. The summer wood in *imbricaria* is nearly solid, broken rather inconspicuously by small amounts of wood parenchyma forming long narrow tangential lines. A few small tracheæ appear distributed radially. In *velutina* the masses of summer wood are as a rule relatively broader and are not nearly so dense, the blocks of wood fibres being broken up by the more numerous, broader and more conspicuous tangential bands of wood parenchyma. The summer wood in *Leana* presents a condition closely approximating that in *velutina* save that the tangential bands of wood parenchyma are slightly less numerous and the growth ring is not so wide. The growth ring is narrower in *imbricaria* than it is in either of the others.

Microscopic Studies

Sections in transverse, tangential, and radial planes were made with a sliding microtome from stems of various sizes up to $2\frac{1}{2}$ cm. in diameter. A part of these sections were cut from living material, the sections being transferred to 70 per cent alcohol and then brought into water for staining; and a part were made from material fixed in picro-corrosive and imbedded in celloidin according to Jeffrey's method.[12] All were stained with Ehrlich's hæmatoxylin and safranin.

[12] *Botanical Gazette*, vol. xxxvii, pp. 456–461, 1904.

IMBRICARIA

Transverse (plate XIII, fig. 1; plate XIV, figs. 1, 4). The pith cells are generally roundish, rather loosely packed together, and fairly uniform in size. The broad pith rays are from three to seven cells in width in the first year's growth and broader in the older stems. The narrow rays, mostly a single cell in width, are poorly defined and inconspicuous. Extending out from between the groups of protoxylem next the pith are rays which begin with a width of three or four cells, but which quickly narrow to the dimensions of the ordinary narrow ray. In older stems secondary broad rays develop by the coalescence of narrow rays.[13] In the broad rays the cells are rectangular, narrow, elongated radially, with oblique tangential walls. In the narrow rays the cells are sometimes squarish in the spring wood, and come to be elongated radially in the summer wood. Protoplasmic connections appear rather conspicuously between the pith cells, between the ray cells, and between the two. Wood parenchyma is rather sparingly distributed among the tracheids and wood cells of the spring wood, and occurs in the summer wood as occasional wavy tangential bands. The cells are larger than the wood cells, are thin walled, roundish, and fairly uniform in size. The wood fibers are triangular to septagonal, largely pentagonal, and vary somewhat in size. In the spring wood they are thin walled and are distributed without special grouping among the large vessels and tracheids. In the summer wood they are massed in blocks of considerable size which are penetrated by occasional tracheids, and bounded by the medullary rays and bands of wood parenchyma. A fairly distinct radial arrangement of the fibers can be made out, which becomes definite with the squarish cells at the outer margin of the sharply defined growth ring. Tracheids are fairly numerous in the spring wood, where they vary considerably in size and shape, being irregularly distributed among the wood parenchyma cells and wood fibers between the large vessels. In the summer wood they are less numerous, are circular in form, and are usually found close to the cells of the pith rays. They are thick walled, with numerous oval bordered pits. The vessels are almost wholly confined to the spring wood where they are

[13] Eames, *Botanical Gazette*, vol. xlix, pp. 161–167, 1910.

large and nearly uniform in size, distributed in a single or at most a double row extending completely across the space between two broad medullary rays. Two vessels closely adjoining each other and even compound vessels are sometimes found (plate XIV, fig. 4). Tyloses are fairly numerous in some of the preparations studied. In the summer wood a few small vessels appear in loose radial chains, diminishing in size toward the outer part of the growth ring. Protoxylem is found next the central pith, in the form of small spiral vessels grouped in definite masses between the bases of the broad medullary rays. In the bast there is considerable development of sclerenchyma, which in young twigs occurs in the form of wavy bands just outside the sieve tissue (plate XIV, fig. 1). In older stems this band becomes broken.

Tangential. The broad pith rays are frequently broken up by oblique strands of wood fibers or parenchyma cells, presenting a decidedly stringy appearance across the ray. These strands disappear in the older wood. The uniseriate rays are straight and parallel, and are rather long, being from three to thirty cells in length, and averaging from ten to fifteen cells long. The cells are roundish, somewhat elongated vertically. The wood parenchyma cells are rectangular, being three times as long as broad. The wood fibers are narrow and straight. The vessels are scalariform with bordered pits, and show occasional tyloses.

Radial (plate XIV, fig. 7). The pith cells are rectangular, with roundish corners, and are arranged in more or less definite wavy vertical rows, being elongated sometimes radially, sometimes vertically. Protoplasmic connections between the cells are prominent. The pith ray cells are similar in form, being irregularly elongated radially. They are one and one-half times as long as broad, and show conspicuous protoplasmic connections. The wood parenchyma cells are also rectangular, averaging nearly eight times as long as broad. Protoplasmic connections are abundant both among these cells and between them and the pith ray cells. The protoxylem vessels usually show two spirals, although occasionally small vessels are found with but a single spiral, and on the other hand the larger ones may have three.

VELUTINA

Transverse (plate XIII, fig. 2; plate XIV, figs. 2, 5). The pith cells are somewhat more variable in size than in *imbricaria*, and their arrangement gives a more compact structure, with smaller intercellular spaces. The narrow pith rays are much more numerous, and stand out sharply against the wood masses as crooked, irregular, uneven lines. The ray cells are a little broader and somewhat longer, and more irregular. Protoplasmic connections occur as in *imbricaria*. Wood parenchyma is more abundant throughout both spring and summer wood, and in the latter is scattered in numerous wavy short tangential chains. Wood fibers are more abundant in the spring wood, especially near the broad rays. In the summer wood they are grouped in smaller masses, giving that part of the growth ring a much less compact and solid appearance. The radial arrangement of the fibers discernable in *imbricaria* is more or less broken up by masses of wood parenchyma, and the growth rings are not so sharply defined. Angular tracheids are plentiful in the spring wood, and roundish ones are scattered sparingly through the summer wood. The vessels of the spring wood are not so abundant or so large as in *imbricaria*, and do not extend so uniformly or so completely across the spaces between the broad medullary rays, but have a tendency to be bunched together into irregular groups. The few summer vessels are somewhat smaller than those of *imbricaria*. Compound vessels, or two vessels closely adjoining, are seldom found in *velutina*. The protoxylem is not massed into a few well-defined areas, as in *imbricaria*, but is scattered, appearing as numerous small groups of a few cells each. The sclerenchyma of the bast, which appears as a band in young twigs and which in *imbricaria* was merely sinuate, is here deeply scalloped.

Tangential (plate XIII, fig. 9; plate XIV, fig. 8). The broad pith rays of the younger stems present a more broken aspect than in *imbricaria*, being traversed with sheets of woody fibers instead of strands. Accordingly the stringy appearance noted in that species is quite wanting here. The uniseriate rays are more numerous than in *imbricaria*, and they average considerably shorter—from five to nine cells. They are not so straight or so uniformly parallel, and their distribution is not so regular. Occasionally they are two cells in width in the middle of a ray.

The wood parenchyma cells and also the wood fibers average somewhat larger in *velutina*, and the latter are not so straight. The vessels show fewer tyloses.

Radial. The pith cells in their vertical arrangement show something of the regularity seen in *imbricaria*, but their greater variability in size and form makes the rows of cells less even and distinct, and the wavy zigzag character of these rows is more pronounced. The pith ray cells average somewhat longer and wider, and tend to be more strictly rectangular, with straighter thicker walls. The wood parenchyma cells average somewhat larger.

LEANA

Transverse (plate XIII, fig. 3; plate XIV, figs. 3, 6). The pith cells in their arrangement present a fairly compact structure, as in *velutina*, but in uniformity of size and shape they are more like *imbricaria*. The uniseriate medullary rays are straight and rather inconspicuous, thus resembling *imbricaria*. The cells, however, are broader and more irregular, as they are in *velutina*. The wood parenchyma is altogether *velutina* like, both in its distribution and arrangement. The radial arrangement of the wood fibers is maintained here, as in *imbricaria* despite the fact that the numerous blocks of wood parenchyma would naturally tend to break it up. Angular tracheids are abundant in the spring wood, while a few roundish ones are to be found embedded in the wood masses of the later growth. The vessels are altogether *velutina* like, in abundance, distribution, and arrangement. The protoxylem is perhaps somewhat less scattered than in *velutina*, but shows none of the distinct massing characteristic of *imbricaria*. In the bast of young stems the band of sclerenchyma presents the deeply scalloped appearance of *velutina*.

Tangential. The broad medullary rays of the younger stems present in their interruption by obliquely running strands, a condition closely resembling that in *imbricaria*. The narrow rays in their number, size, character, arrangement and distribution, are altogether like *velutina*, as are also both the wood parenchyma and the wood fibers. Tyloses occur abundantly in the vessels in some of the preparations studied.

Radial (plate XIV, fig. 9). The arrangement in vertical rows of the pith cells is more distinct and even, and less wavy and

zigzag than in *velutina*, and closely simulates the condition in *imbricaria*. The medullary cells are usually broad, as in *velutina*, although occasional narrow ones are to be found. The ray cells tend to be rectangular, with straight thick walls, here again as in *velutina*. The wood parenchyma cells vary widely in size, both the large ones of *velutina* and the smaller ones of *imbricaria* being here present.

SUMMARY OF MICROSCOPIC STUDIES

From these anatomical studies it appears that, while certain features show remarkable uniformity in form and structure, differences do appear in the size, number, and arrangement of parts. In all these respects it is seen that *Leana* resembles either *imbricaria* or *velutina*, rarely occupying an intermediate position between them. From the table it will be seen that *Leana* resembles *velutina* in the distinctive features of the following characters: annual ring, spring and summer wood, broad rays, broad and narrow ray cells, pith (arrangement of cells), wood parenchyma, wood fibers, vessels (distribution), protoxylem (arrangement), and sclerenchyma of bast. It resembles *imbricaria* in pith cells (size), five bands, narrow medullary rays, some of the wood parenchyma cells, vessels (size), and in tyloses.

Penhallow[14] shows in an anatomical study of Teas hybrid Catalpa that the structural features of the two parents are faithfully transmitted to the offspring. If what Penhallow found to be true for Catalpa obtains in oaks, we have a right to conclude that resemblances such as appear between the oaks in question have a significance in demonstrating actual relationship. In other words, these resemblances furnish a strong evidence of the hybrid nature of Lea's oak.

Comparison With the Type Tree and Others

Leaves of the type tree in general resemble very closely those from the Cedar Point trees, although differing in certain respects. The latter leaves are often more deeply lobed, and their bases tend to be less obtuse than the former. On the other hand,

[14] *American Naturalist*, vol. xxxix, No. 459, pp. 113–136, 1905.

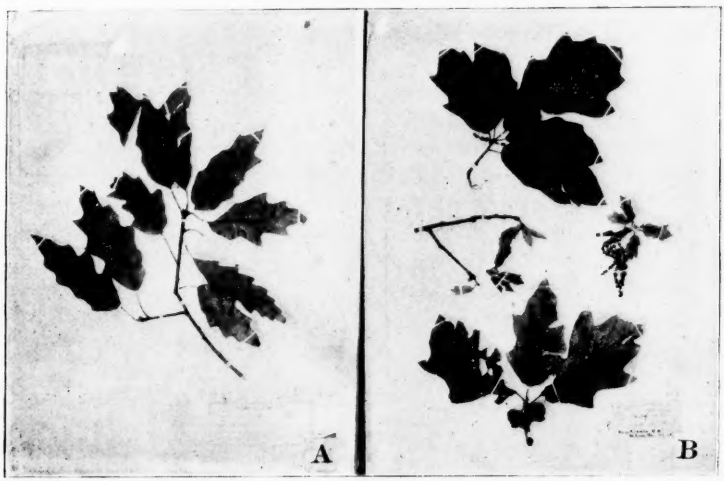
	IMBRICARIA	VELUTINA	LEANA
Annual rings	Sharply defined	Poorly defined	Poorly defined
Spring wood	Coarse, uniform	More compact, not uniform	More compact, not uniform
Summer wood	Solid, compact, narrow	Broken, broad	Broken, less broad
Pith	Small	Large	Long and narrow
Pith cells	Loosely packed uniform size	Closely packed variable size	Closely packed uniform size
	Even vertical rows, wavy	Uneven vertical rows zigzag	Fairly even rows, wavy
Broad pith rays	Five pairs, forming bands	Numerous, no bands	Numerous, bands
	Broken by strands	Broken by sheets	Broken by both
Cells	Narrow with oblique walls	Wider, more strictly rectangular	Broad, rectangular
	Thin walls	Thick walls	Thick walls
Narrow pith rays (transverse)	Straight, parallel, inconspicuous	Crooked, not parallel, conspicuous	Straight, parallel, inconspicuous
(tangential)	Long, few, regularly distributed	Short, numerous, irregularly distributed	Short, numerous, irregularly distributed
Cells	Uniform, small	Irregular, larger	Irregular, larger
Wood parenchyma	Scarce in spring wood	More abundant in spring wood	More abundant in spring wood
	Narrow bands in summer wood	Broader masses in summer wood	Broader masses in summer wood
Cells	Smaller	Larger	Some larger, some smaller
Wood fibers	Distinct radial chains	Broken radial chains	Distinct radial chains
Cells	Smaller, straight	Larger, not straight	Larger, not straight
Vessels	Inter-ray space filled uniform layer	Space not filled Bunched	Space not filled Bunched
	Large, uniform size	Smaller, various sizes	Smaller, somewhat uniform
Protoxylem	Massed	Scattered	Somewhat scattered
Bast sclerenchyma	Wavy band	Deeply scalloped	Deeply scalloped
Tyloses	Sometimes many	Fewer	Sometimes many

specimens from Chickering (fig. 1, *A*) and Ward (plate XII, fig. 4) show a condition of greater acuteness than do the leaves from Cedar Point. Again, the margins between the lobes of the leaves of the type tree show a tendency toward rolling back which is not characteristic of the Cedar Point forms, or of any other representatives of this oak that have come under my notice. Taken all in all, however, the Cedar Point leaves approach nearer the type than any other forms examined.

The acorns compare very closely in all the forms examined. The transversely cut stem of Lea's tree shows the five distinct bands bounded by the ten primary pith rays coming off at the angles of the pith, as noted for *imbricaria*, and as found in the Cedar Point *Leana*. There are also a few additional broad rays,

which, although fewer in number than the Cedar Point specimens show, are equally distinct (plate XIII, fig. 6). Further study of the stems has not been made.

In considering these observations it must be noted that in respect to leaf characters the Cedar Point trees show wide variability, including differences in form, outline, lobing, apex, base, and petiole. Accordingly it would be unreasonable to expect that differences might not exist between them and the type tree. Furthermore, an equally wide variability could be shown to exist in *velutina*, as found at Cedar Point and elsewhere, and could doubtless be demonstrated for many other oaks. In fact,



A. *Quercus Leana* from Washington, D. C. Branch showing leaves. J. W. Chickering, Jr; × $\frac{2}{13}$.

B. *Quercus Leana* from Belleville, Ill. Branches showing leaves, flowers and fruit. George Engelmann; × $\frac{2}{13}$

if *Leana* be a hybrid, with *velutina* in its parentage, it would be altogether reasonable to suppose that the offspring had received this character of instability, along with other qualities in its inheritance. So neither from leaf characters, nor from structural features so far as studied, does evidence appear to preclude the placing of the Cedar point representatives in the same category with Lea's type tree.

Conclusions

The facts herein presented seem amply to justify the conclusion that the several trees at Cedar Point are hybrids between the *Quercus imbricaria* and the *Quercus velutina* found there, and that the type tree and others like it are hybrids between *imbricaria* and *velutina* because:

1. The fruit is sterile so far as is known.
2. The leaves are intermediate between those of *velutina* and *imbricaria*.
3. The stem in both gross and microscopic anatomy shows characters indicating relationship with both *imbricaria* and *velutina*.
4. The fruit is very much like that of *velutina* and is wholly unlike that of *Q. rubra*.
5. The staminate flowers of *velutina* are mature at the proper time for effecting cross pollination.
6. The trees are invariably isolated from each other and are always found by the side of an *imbricaria*.

Furthermore from the last two facts given, together with Mr. Ward's account of the *Leana* raised from an acorn of an *imbricaria* tree, we may conclude that the maternal parent is *imbricaria*, and the paternal, *velutina*.

Acknowledgments

I wish to acknowledge my indebtedness and express my appreciation to Professor Stickney for his assistance in every part of this work. I also wish to thank Miss Lett, and Dr. Holden for the material from the type tree, and Professor Jennings, of the Carnegie Museum, for the loan of other specimens of *Leana*.

Plate XI

Fig. 1. *Quercus imbricaria* from Cedar Point, O. Branch showing leaves and fruit; × $\frac{1}{6}$.

Fig. 2. *Quercus velutina* from Cedar Point, O. Branch showing leaves and fruit; × $\frac{1}{6}$

Fig. 3. *Quercus Leana* from Cedar Point, O., tree *A*. Branches showing leaves; × $\frac{1}{6}$.

Fig. 4. *Quercus Leana* from Cedar Point, O., tree *B*. Branch showing leaves. The entire leaf at the end of the branch has a wavy margin and is crisped; × $\frac{1}{6}$.

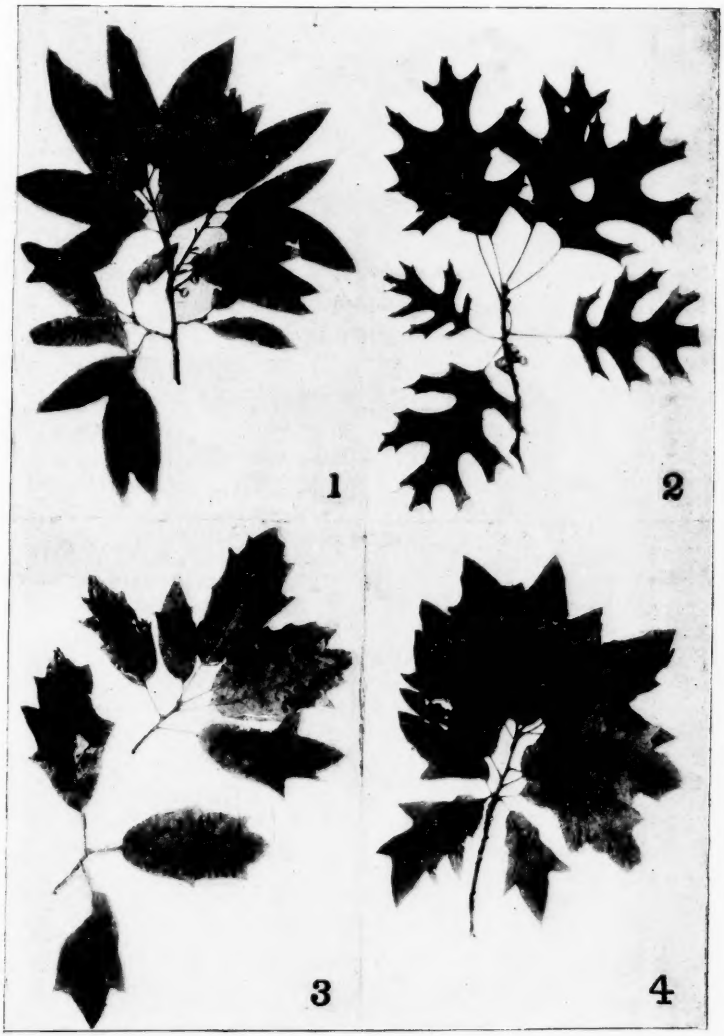

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PLATE XII

FIG. 1. *Quercus Leana* from Cedar Point, O., tree *B*. Branch with imbricated leaves; entire leaves at end of year's growth; $\times \frac{1}{6}$.

FIG. 2. *Quercus Leana* from Cedar Point, O., tree *B*. Branch showing leaves resembling juvenile leaves of *velutina*; $\times \frac{1}{6}$.

FIG. 3. *Quercus Leana* from Cincinnati, O. Leaves from the type tree, $\times \frac{1}{6}$.

FIG. 4. *Quercus Leana* from Washington, D. C. Branches showing leaves, flowers, and fruit. Lester F. Ward; $\times \frac{1}{6}$.

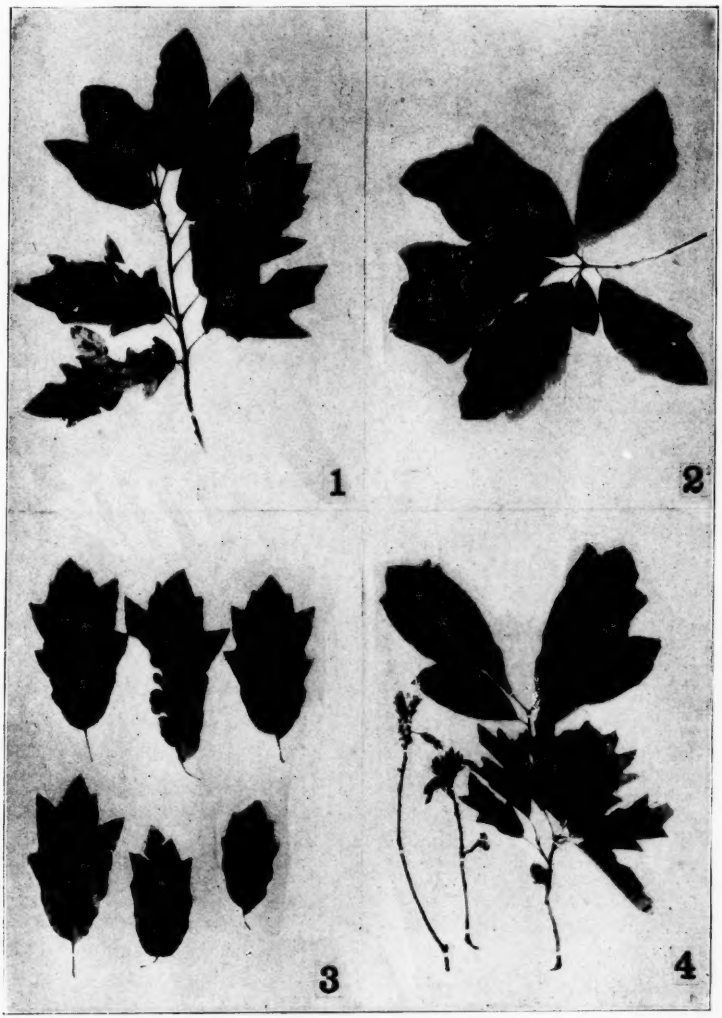
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Plate XIII

Fig. 1. *Quercus imbricaria* from Cedar Point, O. Twig (photographed through a hand lens) showing the five bands made by the five pairs of broad medullary rays and the enclosed wood; × 4.

Fig. 2. *Quercus velutina* from Cedar Point, O. Twig showing numerous broad medullary rays, five bands not distinct; × 4.

Fig. 3. *Quercus Leana* from Cedar Point, O. Twig showing numerous broad medullary rays; five bands somewhat distinct; × 4.

Fig. 4. *Quercus rubra* from Denison Campus. Twig showing numerous broad medullary rays; × 4.

Fig. 5. *Quercus velutina* from Columbus, O. Twig showing numerous broad rays; × 4.

Fig. 6. *Quercus Leana* from Cincinnati, O. Twig from type tree, showing broad medullary rays; two pairs and their bands are prominent; × 4.

Fig. 7. *Quercus coccinea* from Denison Campus. Twig showing very numerous, less distinct, broad medullary rays; × 4.

Fig. 8. *Quercus alba* from Denison Campus. Twig showing wavy lines, no broad medullary rays; × 4.

Fig. 9. *Quercus velutina*. Tangential section showing protoplasmic connections between wood parenchyma cells; × 285.

SUPPOSED HYBRID OF THE BLACK AND SHINGLE OAKS

EARL HARRINGTON FOOTE

PLATE XIII

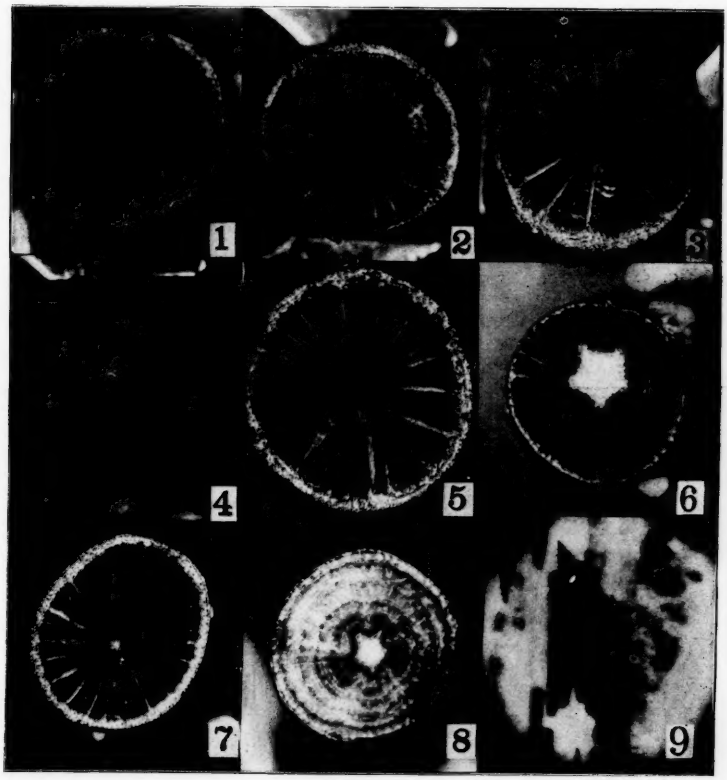


PLATE XIV

FIG. 1. *Quercus imbricaria.* Transverse section showing small pentagonal pith and ring of sclerenchyma in bark: × 6.

FIG. 2. *Quercus velutina.* Transverse section showing very large pentagonal pith and deeply scalloped ring of sclerenchyma in bark: × 6.

FIG. 3. *Quercus Leana.* Transverse section, elongated, narrow pentagonal pith, and deeply scalloped ring of sclerenchyma in bark: × 6.

FIG. 4. *Quercus imbricaria.* Transverse section showing distinct annual ring, large uniform vessels in one or two rows in spring wood, few small vessels in radial chains in summer wood, broad medullary ray, uniseriate rays (inconspicuous), wood parenchyma cells in wavy tangential bands: × 285.

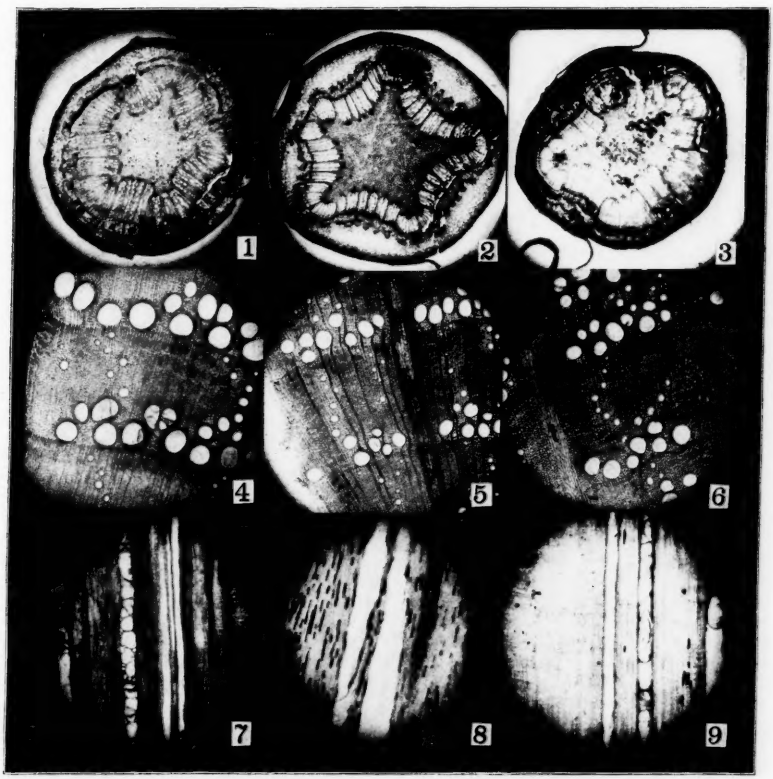
FIG. 5 *Quercus velutina,* Transverse section showing annual ring, smaller vessels varying in size in groups in spring wood, few small ones in radial chains in summer wood, broad medullary rays, prominent uniseriate rays, wavy tangential masses of wood parenchyma in summer wood; × 285.

FIG. 6. *Quercus Leana.* Transverse section showing annual ring, vessels showing tendency toward grouping, small ones distributed radially in summer wood, broad medullary rays, uniseriate rays (inconspicuous), wavy tangential masses of wood parenchyma in summer wood; × 285.

FIG. 7. *Quercus imbricaria.* Radial section showing vessels with numerous tyloses; × 285.

FIG. 8. *Quercus velutina.* Tangential section showing broad and uniseriate medullary rays, vessels without tyloses; × 285.

FIG. 9. *Quercus Leana.* Radial section showing vessel with tyloses; × 285.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A CASE OF PRE-GLACIAL STREAM DIVERSION NEAR ST. LOUISVILLE, OHIO[1]

HOWARD CLARK

On account of the many interesting features in its drainage development, Ohio, in recent years, has attracted much attention among students of physiography. Among the first in Ohio to become interested was Dr. W. G. Tight,[2] who in a general way worked out some of the fossil stream courses of the central part of the state, and, in much detail, the drainage changes of southeastern Ohio, parts of Kentucky and West Virginia. In this work he dealt not only with the evolution of the Ohio River itself but also with the changes observed in many of its tributary valleys, especially in the Muskingum and Scioto valleys. In the western part of the state, Dr. J. A. Bownocker has studied several drift-buried channels, correlating them with a major stream that probably flowed to the west.[3] Several other workers have carried on similar studies in other parts of the state.

Many theories have been advanced in accounting for these changes in drainage: (a) piracy, (b) glaciation, and (c) diastrophism. In some cases more than one factor, it has been thought, was operative. But there is a lack of agreement among students of the subject in assigning relative weights to these factors. Dr. Tight[4] urged glaciation as the principal cause for the reversals in Ohio; Mr. Leverett[5] also gives much weight to this factor. Dr. Carney[6] concludes from more recent studies in parts of

[1] This work was done under the direction of Professor Carney, as an assignment in an undergraduate course.

[2] U. S. Geol. Surv., *Professional Paper, No. 13,* 1902.

[3] *American Geologist,* vol. xxii, pp. 178–182, 1899. Ohio Academy of Science, *Special Paper, No. 3,* pp. 32–45, 1900.

[4] *Bull. Sci. Lab. Denison Univ.,* vol. viii, pt. II, pp. 35–61, 1894.

[5] U. S. Geol. Surv., *Monograph xli,* pp. 196–198, 1902.

[6] *Bull. Sci. Lab. Denison Univ.,* vol. xiii, pp. 139–153, 1907, vol. xiv, pp. 128–134, 1909.

FIG. 1. Portion of the Newark topographic sheet. The three sets of parallel lines locate the cross-sections drawn in fig. 4.

Licking county that the stream reversals in this area were accomplished pre-glacially as a result of a differential land movement; Mr. E. R. Scheffel,[7] from work on drainage changes near Granville, Ohio, and Mr. K. F. Mather,[8] from a similar study of the Licking river near the "Narrows," confirm this theory.

The present discussion proposes no new theories concerning drainage changes; it directs attention to a case of reversal in which glaciation may, to some extent, be a factor.

Discussion

The region here considered, a portion of Licking County, Ohio, contains the head-water area of Rocky Fork which has its source near the east wall of the North Fork of the Licking Valley, about one and one-half miles northeast of St. Louisville. From is place of origin the Rocky Fork flows in a northeasterly direction for about three miles, turning then to the east for two miles, continuing thence approximately south, and joining the Licking River near Hanover.

The Rocky Fork rises in a mature valley whose walls gradually converge down-stream, coming closest together about six miles from its source, where the present stream flows for some distance through a narrow gorge; below this narrow segment, the walls diverge to the south. Thus both up-stream and down-stream from the gorge is a wider valley.

The topographic map of this region (fig. 1) suggests that segments C and B of the Rocky Fork Valley were once connected with the Licking; the trend of this portion of the valley, and the fact that its walls flare towards the Licking Valley at St. Louisville are the obvious details which support such an inference. The stream which carved these segments flowed westward from near the eastern end of B.

But such irregularity in the width of a valley is sometimes the result of varying hardness in the rock horizons through which the stream is cutting. The rock structure itself, in this area, is not of a nature that gives such differential responses to weathering; the formations exposed are the Pottsville, Logan, and Black Hand, none of which are here very resistant.

[7] *Bull. Sci. Lab. Denison Univ.*, vol. xiv, pp. 162–174, 1909.
[8] *Ib.*, pp. 183–187.

Evidently the Rocky Fork, in parts B and C, shows reversal; six miles of the valley that formerly carried a westward flowing stream now carries a stream flowing in the opposite direction. What caused this reversal?

The drift barrier. Just east of St. Louisville, at the junction of part C with the Licking, is a heavy deposit of glacial drift which forms a barrier across the mouth of the former valley; this moraine barrier has about the same altitude as the valley walls which bear a veneer of till. The barrier presents a steep and irregular front to the south, (fig. 3, *A*) the ice-contact side,

FIG. 2. Looking westward across the outwash plain east of St. Louisville. The drift barrier forms the sky-line.

while its northern front blends into an outwash plain which slopes gently and very regularly into the valley (fig. 2).

Along the south front of the barrier, about midway between the rock walls on either side and eighty feet below the highest elevation of the drift, is a well seventy feet deep, entirely in glacial drift. Other well records were obtained, but none were deep enough to establish the maximum thickness of the barrier. As seen in exposures, the drift is made up of gravel, sand and boulders of all sizes imbedded in a matrix of yellow clay; occasionally a large granite boulder is seen, two or three feet in

diameter. Scattered throughout the mass of drift are also many fragments of local rock principally of the Logan formation, which

FIG. 3. *A*. Southern slope of the drift barrier east of St. Louisville, *B*. An eroded drift surface a short distance east of the area shown in *A*.

had been plucked from the sides of the neighboring valley by the ice.

An important feature of this drift is the extent to which it has suffered weathering. Fig. 3, *B.* shows its irregular surface, and the interlocking spurs in one of the many small valleys which have been cut back into the drift. Its age is also indicated by the degree to which the boulders have suffered chemical change; some of the fine-textured crystalline rocks, which would be expected to resist weathering more than the others, on being broken, show an altered band nearly one-half inch wide. These

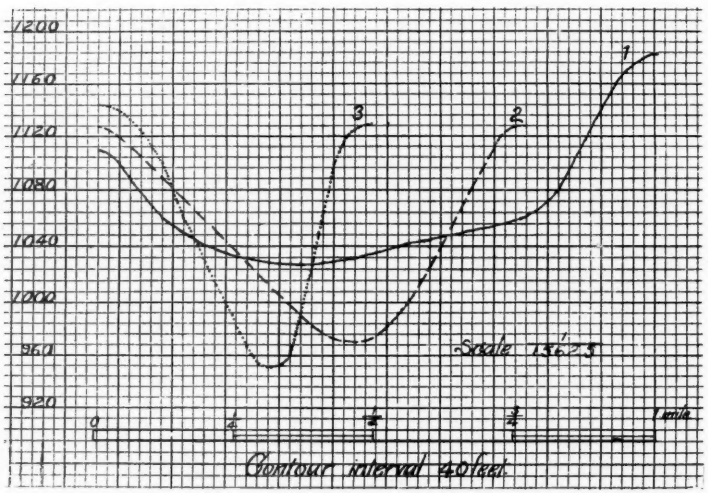

FIG. 4. Cross-sections of the Rocky River valley arranged in down-stream order, 1 to 3; for their location, consult fig. 1.

facts indicate a considerable length of time since the drift was deposited. Leverett maps it under Illinoian.[9]

A possible lake. The glacier standing across this south opening valley must have produced an ice-front lake, if the drainage was then flowing southward. The size of this lake would be determined by the location and altitude of its overflow channel. If the outlet was in segment A, the narrowest part of the valley,

[9] *Loc. cit.*, p. 342.

over a divide against which Rocky Fork then headed, the lake was deeper than if the outlet was at the west end of part B; under the former condition the lake would have been about twice as large as under the latter; in either case we would expect to find alluvial fans, deltas, lake clay and beaches along the valley walls of the present stream course. Such evidences of a former lake would seem inevitable, considering the great length of time that would be required to change the supposed rock col into the present channel. But no shoreline structures are to be found; therefore it is questioned whether a lake ever stood here.

Part C. A swampy condition exists in part C, extending from the margin of the outwash plain northward for about one mile and gradually disappearing. The soil is of a black mucky nature and contains a great deal of vegetable matter. In several places where attempts have been made to dispose of the tall grass by firing it, this black peaty soil has burned to a depth of over a foot. There is no surface evidence of unmodified drift deposits found at any great distance from the margin of the outwash plain. This part of the Rocky Fork Valley has a very low gradient; the farmers have to under-drain the fields to secure sufficient drainage to carry on agriculture.

Another hypothesis. Formerly a stream flowed westward from a divide located in part A; and another stream flowed southward through the present course of the Rocky Fork; this divide is indicated approximately by cross-section 3 (fig. 1). The capture of the headwater section of the west-flowing stream by the Rocky Fork was indicated by differential tilting. A new divide was established in part B; this divide progressed to the west, probably to the position indicated by cross-section 2. This secondary divide probably represents the position which the east-flowing and west-flowing streams held with reference to each other at the time of the Illinoian ice invasion; it is at this stage in their life history that the reversal of part C of the present stream must have taken place. This part of the valley was glacially aggraded in the retreat of the ice to the barrier position east of St. Louisville; outwash deposits tended further to establish a slope towards the secondary divide.

Conclusion

This study has attempted to show that this case of stream diversion is due to a combination of causes: first, that of land warping which induced the piracy of part B by the Rocky Fork, pushing the divide back to a position representing approximately the former level of the swamp which occupied part C; second, that the glacier, first by drift deposits left in part C, and later by constructing a drift barrier across its southern end, ponded the stream which flowed into the Licking, and, through outwash deposits, formed a swampy condition, eventually reversing the direction of flow, and adding that stream also to the present Rocky Fork.